New Zealand Journal of Agricultural Research, 2003, Vol. 46: 37–47
0028–8233/03/4601–0037 $7.00/0

Sodium requirements for temperate pastures in New Zealand: a review

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Abstract Sodium (Na) is not an essential plant nutrient for forage pasture species but is required for optimal animal health and production. The distribution of Na in New Zealand pastures and soils is reviewed and evidence discussed indicating that the incidence of Na deficiency in animals, particularly dairy cows, is likely to increase with time. Vulnerable regions within New Zealand are identified. The results from New Zealand trials confirm that animal production responses to Na supplementation or fertiliser Na are unlikely to occur if the pasture Na concentration is greater than 0.10%. Results from trials examining the effects of Na fertiliser on pasture production and chemical composition are also reviewed. On soils with adequate soil potassium, Na has no effect on pasture production and applications of 50–100 kg NaCl/ha are sufficient to increase pasture Na concentration above the critical level for animal production (0.10% dry matter (DM)), even on soils with low initial soil Na concentrations (MAF Quick Test (QT) <10, 0.20 cmole Na kg^{-1}). Methods for correcting Na deficiency in animals are also reviewed.

Keywords animals; fertilisers; pastures; sodium; soil fertility

A02018
Received 18 March 2002; accepted 3 October 2002

INTRODUCTION

Sodium (Na) is essential for animal health and production (Towers & Smith 1983) but is not an essential element for the growth of pasture species (Marschner 1995). The need to either supplement pasture-fed animals with Na, or fertilise pastures with Na, is therefore dictated by the Na requirement of the animal. Whether a site is Na deficient depends on the Na concentration in the pasture and the intake of pasture dry matter (DM).

Smith & Middleton (1978) reviewed pasture analyses from over 3000 sites from throughout New Zealand and concluded that the proportion of sites Na deficient with respect to adequate animal health was 67, 26, and 9% for dairy, beef, and sheep animals, respectively. These figures were based on Agricultural Research Council (1965) recommendations for the minimum herbage Na concentration for optimal animal health of 0.20, 0.10, and 0.07%, respectively. Based on subsequent work, Towers & Smith (1983) suggested provisional critical herbage Na concentration, at which or below which pasture-fed animals are likely to respond to Na supplementation of 0.09% for lactating cattle and 0.05% for lactating sheep. These minimum adequate levels apply to pasture-fed sheep and beef animals under New Zealand conditions.

More recently, O'Connor et al. (2000) demonstrated production responses to Na supplementation in lactating dairy cows grazing pastures with an average Na concentration of <0.05% and McDonald et al. (2002) reported no responses in lactating dairy cows to Na supplementation, on pastures with an average of 0.10% Na. These results suggest that the minimum herbage concentration for dairy animals fed all-pasture diets in New Zealand lies between 0.05 and 0.10%, in which case it is less than the level previously set by the Agricultural Research Council (1965). (See Towers et al. (1984) for a discussion of this point.) In contrast, Phillips et al. (2000) have suggested that pasture Na concentrations should be at least 0.40% for optimal animal production and health. This discrepancy has important implications for New Zealand in terms of defining Na fertiliser and animal supplement requirements and needs resolution.

Furthermore, there is evidence (Monaghan et al. 2001; Ledgard et al. 2001) that some regions in New Zealand are in a negative balance with respect to Na inputs and losses, at least for dairy farming. It is likely, therefore, that the incidence of Na deficiency in dairy animals, and possibly in intensive beef operations, will increase in the future.

Given these recent advances, the purpose of this review is to re-examine the literature on the Na requirements of pasture-fed grazing animals, and on the management of the Na fertility in pastoral soils, with a view to clarifying and updating soil, pasture, and animal Na requirements in New Zealand. This review focuses exclusively on research relevant to the Na requirements of temperate pastures grazed *in situ* by animals. The large bodies of research on animal Na requirements derived from ration-fed animals and from tropical and semi-tropical pastures are not included.

FUNCTIONS OF Na

Animals

Sodium is the principal cation in the extracellular fluid and plays a major role in regulating the composition of blood, saliva, and extracellular fluid. Thus, it is involved in the maintenance of osmotic pressure, water balance, and acid-base balance. It also has a specific role in the transmission of nerve impulses and muscle contraction (Towers & Smith 1983). Towers & Smith (1983) provide an overview of the metabolism of Na together with an account of the deficiency symptoms and diagnosis of Na deficiency in animals.

Plants

Similar to its role in animal metabolism, the functions of Na in the plant include the maintenance of osmotic pressure and water balance, and the transport mechanisms within the plant. Potassium is also involved in these functions and to some extent, depending on plant species, Na and K are interchangeable in these roles. In some plants—the natrophobes—Na has a specific role in activating the enzyme system within the plant (Marschner 1971, 1995). Based on this understanding, Marschner (1995) classified plants into four groups (Fig. 1). At one extreme, some natrophiles have a specific requirement for Na to achieve maximum growth and will respond to fertiliser Na applications if soil Na is deficient, irrespective of the soil K level. To a large extent the non-specific roles of Na and K are inter-replaceable. In contrast, the natrophobes do not require Na for optimal growth and will not respond to Na, even if the soil is K deficient. There is little or no potential for Na and K substitution. Marschner (1995) allows for variations between these two extremes.

Smith et al. (1978, 1983) have classified most of the important temperate pasture species found in New Zealand according to whether they are natrophobes or natrophiles. Importantly, they showed that while the concentration of Na in their roots was similar, natrophobes were differentiated from natrophiles by the lower concentration in their shoots, when grown at a common external Na concentration. It appears that although the natrophobes will take up soil Na into their roots, they do not translocate this Na to the plant tops. Within the New Zealand context, pasture species such as kikuyu (*Pennisenum clandestinum*), paspalum (*Paspalum dilatatum*) and lucerne (*Medicago sativa*) are natrophobes (Table 1) and the Na concentrations in their leaves are rarely >0.05%, even when grown in the presence of adequate Na. It is not surprising therefore that the first reports of Na deficiency in New Zealand occurred with animals feeding on lucerne-based diets (Joyce & Brunswick 1975).

DISTRIBUTION OF Na IN SOILS AND PASTURE

A New Zealand map of "available" topsoil soil Na was published in 1962 (Metson 1962). This was based on the Na concentration of sweet vernal (*Anthoxanthum odoratum*) grown in 400 representative soils, and showed high concentrations of Na in soils exposed to the prevailing salt-laden westerly and southerly winds. Low levels occurred in inland areas of both islands and particularly the Central Plateau of the North Island and the Canterbury Plains and Central Otago regions of the South Island. Smith & Middleton's (1978) results, based on 3000-odd pasture samples, showed a similar distribution and emphasised those regions most susceptible to Na deficiency as the pumice soils of the Central Plateau in the North Island and the Marlborough and Central Otago regions in the South Island.

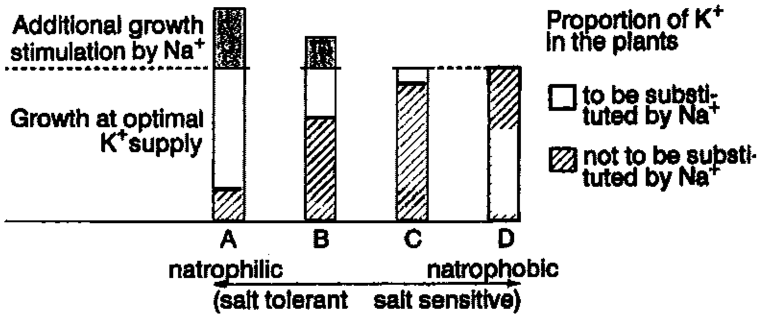

Fig. 1 Classification of crop plants according to the extent to which sodium can replace potassium and affect plant growth (Marschner 1995, fig. 10).

Of the four exchangeable cations in the soil, Na is normally present in the lowest concentration, typically 0.1–0.3 cmole kg^{-1} (5–10 MAF QT units—see Cornforth & Sinclair 1984), and rarely exceeds 0.5 cmole kg^{-1} (20–25 QT units) (New Zealand Soil Bureau 1968; Edmeades 1982; Edmeades et al. 1985). However, because it is less strongly held by the soil cation exchange sites, it is frequently the dominant cation in soil solutions (Edmeades et al. 1985).

Sodium budgets have been constructed for typical dairy farms in Southland (Monaghan et al. 2001) and the Waikato/Taranaki (Ledgard et al. 2001). The essential results are presented in Table 2. These regions coincide with areas of high soil and plant Na according to Metson (1962) and Smith & Middleton (1978). In both regions rainfall is the greatest source of Na and leaching is the largest loss. On average, there is a slight negative balance of Na suggesting that, given sufficient time, soil Na levels will decline. However, it is known that there is considerable variation in annual leaching losses—in the Waikato they ranged from 13–36 kg Na/ha per year depending on the rainfall—and it reasonable to assume that annual inputs in rainfall will also vary from year to year. It is possible,

Table 1 Sodium content of the shoot and roots of common pasture species grown at a common external Na concentration in sand culture (adapted from Smith at al. 1978). DM, dry matter.

Species[1]	Sodium content (%DM) Shoots	Sodium content (%DM) Roots	Ratio (Na shoots:Na roots)
Natrophiles			
Phalaris	0.44	0.13	3.4
Yorkshire fog	0.40	0.11	3.6
Subterranean clover	0.36	0.25	1.4
Cocksfoot	0.35	0.18	1.9
White clover	0.35	0.20	1.8
'Nui' ryegrass	0.34	0.14	2.6
Prairie grass	0.34	0.24	1.4
'Ruanui' rygrass	0.33	0.15	2.2
Lotus penduculatus	0.30	0.23	1.3
Tall fescue	0.24	0.19	1.3
Natrophobes			
Browntop	0.17	0.20	0.9
Meadow grass	0.17	0.24	0.7
Paspalum	0.06	0.28	0.2
'Kikuyu'	0.05	0.22	0.2
'Timothy'	0.04	0.24	0.2
Lucerne	0.04	0.42	0.2

[1]See Smith et al. (1978) for botanical names and cultivars.

therefore, that in any given year Na inputs and losses may be in balance in these regions. Further long-term research is required to examine this.

There is evidence (Ledgard et al. 2001) that Na inputs via rainfall range from c. 120 kg Na/ha per year close to the west coast and decline rapidly with distance from the westerly coast, down to c. 5 kg Na/ha per year in the Central North Island. This is, of course, consistent with the distribution of soil and plant Na levels discussed earlier. It is predictable, therefore, that the central regions of both islands are in a negative balance with respect to Na and that the soils will be gradually depleted of Na. This problem is exacerbated by the fact that the soils in these regions have a lower cation exchange capacity and therefore less capacity to hold Na against leaching. This is particularly so for the pumice soils in the North Island Central Plateau.

EFFECTS OF Na ON PASTURE

Production

The effects of Na fertiliser applications on pasture growth in New Zealand have been examined in five trials (Table 3). One of these trials was on a K-deficient site, and the others were on soils with medium to high K status. In all cases the dominant pasture species were natrophiles (e.g., white clover (*Trifolium repens*) and ryegrass (*Lolium perenne*)).

Fertiliser Na applications had no significant effects on pasture yield except in the trial on the K-deficient allophanic soil (McNaught & Karlovsky 1964). Because of its uniqueness, the results are reproduced in Table 4. This site was K deficient (soil K 0.29 me/100 g, MAF QT K = 4) but had a high soil Na concentration (soil Na 0.45 me/100 g, MAF QT Na = 200). Na fertiliser increased pasture yields, but only in the absence of applied K. This is probably an example of Na substituting for K in the plant transport system, by mobilising K from the plant roots to the tops. Note, however, that the response to NaCl alone, even at the highest rate, was only c. 25% (+ 3230 kg DM/ha above control) of the response obtained by the same input of KCl alone (+ 12600 kg DM/ha above control), and that no combination of Na + K achieved the same yield as KCl alone. These results demonstrate that Na can only partially substitute for the role of K and that maximum yield can only be achieved if the total requirement for K is met.

The remaining trials (Table 3) confirm that where soil K status is adequate for maximum production (i.e., soil MAF QT K > 7–10), Na fertiliser has no effect on pasture yield, at least on predominantly ryegrass/white clover pastures.

Table 2 Sodium (NA) nutrient budgets for Southland and the Waikato (Monaghan et al. 2001, Ledgard et al. 2001).

		Amounts of Na (kg ha/yr)	
		Southland	Waikato
Inputs	Fertiliser	1	1
	Rainfall	20	35
Outputs	Milk and meat	4	6
	Transfer	2	2
	Leaching	29	40
Balance		−14	−12

Nutrient concentrations

The results from the trial reported by McNaught & Karlovsky (1964) and referred to above, are shown in Fig. 2. These show that on a K-deficient soil with a relatively high soil Na level, applications of KCl had a large positive effect on plant K concentrations, and a large negative effect on plant Na (−100%) (Fig. 2A), noting that in this case the initial plant Na concentration was low. However, fertiliser Na increased both plant Na and K concentrations (Fig. 2B), supporting the idea that Na mobilises K from the plant roots, as suggested earlier. There was no evidence from this trial (results not shown) that Na fertiliser increased soil K availability.

The effects of fertiliser KCl on plant Na concentrations are much smaller on soils with medium to high soil K levels. O'Connor et al. (1989) reported depressions of c. −10% (not shown), similar to the results reported by Smith et al. (1983) on a pumice soil (Fig. 3). Note that in this trial, applications of NaCl of 50 kg/ha, in addition to KCl, were sufficient to maintain the plant Na concentrations at the untreated control level. O'Connor et al. (1989) examined the effect of fertiliser Na on pasture Na concentrations in three diverse soil groups. These results (Fig. 4), taken together with those in Fig. 3, suggest that the application of 50 kg/ha NaCl will be sufficient in most situations (i.e., where MAF QT Na > 5 and MAF QT K > 6) to achieve pasture Na concentrations above the minimum required for adequate animal health (viz 0.10%—see discussion later).

Table 3 Pasture trials in New Zealand examining the effect of sodium (Na) on pasture production and composition. DM, dry matter; –, data not available or not given.

Soil group	Treatments	Control Na concentrations		Control K concentrations		Response to Na	Comments	Reference
		Soil (MAF Quick Test units)	Plant (%DM)	Soil (MAF Quick Test units)	Plant (%DM)			
Allophanic	3 rates of NaCl and KCl plus 4 Na:K combinations	QT 25	0.27–0.56	QT K 3	1.4–2.0	Response to NaCl (see Table 4)	Site K deficient Response to KCl (see Table 4)	McNaught & Karlovsky (1964)
Pumice	5 rates NaCl + 2 rates KCl	QT 5	0.07	QT 6–12	3.6–4.3	No response	Effects of NaCl on plant Na lasted 30 weeks KCl had small effect (–10%) on plant Na	O'Connor et al. (1989)
Allophanic	5 rates NaCl + 2 rates KCl	QT 5	0.12	QT 6–12	3.6–4.3	No response	Effects of NaCl on plant Na lasted 30 weeks KCl had small effect (–10%) on plant Na	O'Connor et al. (1989)
Organic	5 rates NaCl + 2 rates KCl	QT 8	0.06	QT 6–12	3.6–4.3	No response	Effects of NaCl on plant Na lasted 30 weeks KCl had small effect (–10%) on plant Na	O'Connor et al. (1989)
Allophanic	3 rates KCl + 1 rate NaCl + 2 K/Na combinations	–	0.14–0.16	–	2.5–3.8	No response to Na or K	KCl depressed plant Na but this was offset by 50 kg/ha NaCl	Smith et al. (1983)

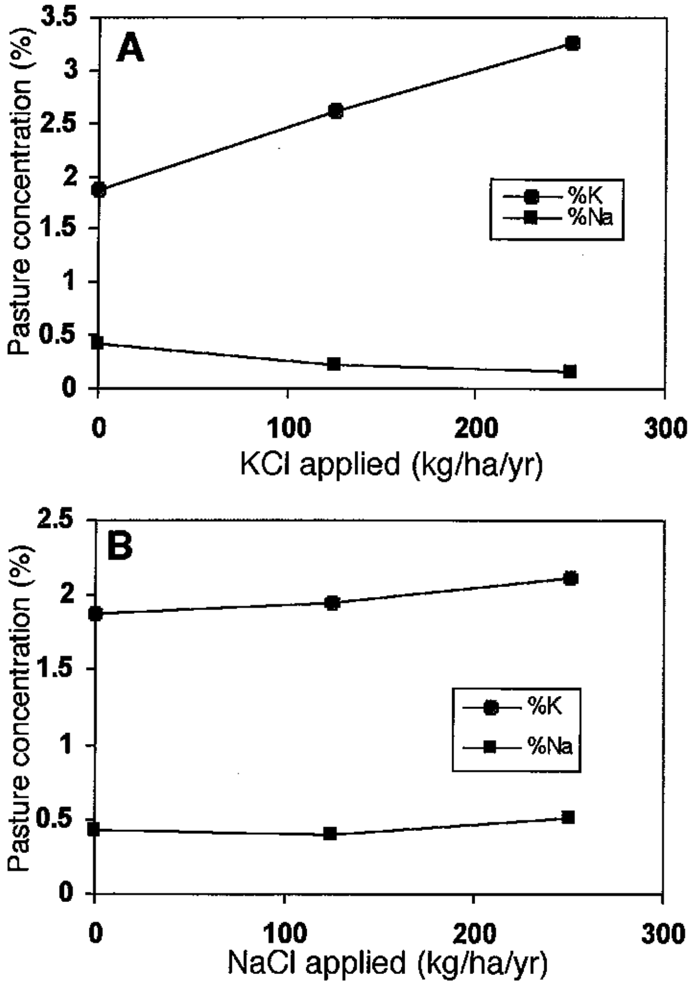

Fig. 2 The effect of **A**, fertiliser potassium on pasture sodium and potassium concentrations; and **B**, of sodium fertiliser on pasture potassium and sodium concentrations (from McNaught & Karlovsky 1964).

Table 4 Effects of sodium (NA) and potassium (K) fertiliser applied alone or in combination on pasture production on an Allophanic soil (McNaught & Karlovsky 1964). DM, dry matter; LSD, least significant difference.

Treatments (annual applications)	Total production for control and absolute increase of treatment over control (kg DM/ha 1954–58)	Relative production 1954–58 (control = 100)
Control	25 500	100
NaCl (125 kg/ha)	2 400	109
NaCl (250 kg/ha)	3 230	113
KCl (125 kg/ha)	8 120	132
KCl (250 kg/ha)	12 600	149
NaCl/KCl (1:1) (125 kg/ha)	5 070	120
NaCl/KCl (1:1) (250 kg/ha)	10 520	141
NaCl/KCl (3:1) (250 kg/ha)	7 010	127
NaCl/KCl (1:3) (250 kg/ha)	10 610	142
LSD ($P < 0.05$)	2 500	110

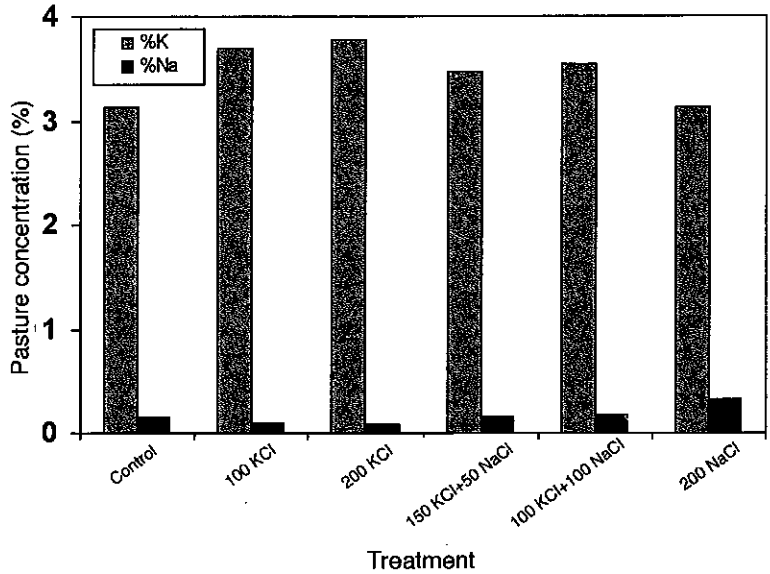

Fig. 3 Effect of fertiliser potassium and sodium on the concentrations of potassium and sodium in pasture (based on data from Smith et al. 1983).

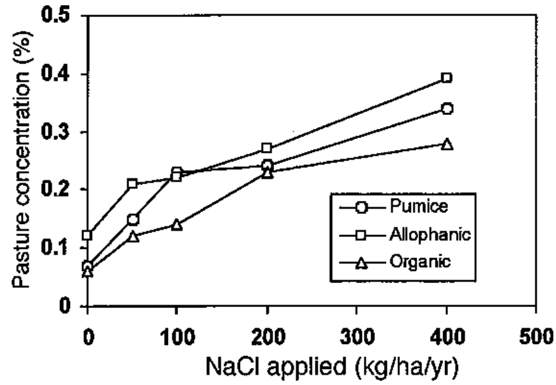

Fig. 4 Effect of fertiliser sodium on the pasture sodium concentrations on three soil groups in New Zealand (based on data from O'Connor et al. 1989).

EFFECTS OF Na ON ANIMALS

The effects of Na supplementation or fertiliser applications on animal production have been measured in a number of trials in New Zealand. The essential results are summarised in Table 5. Based on those results available up to 1983, and taking into account other factors such as animal physiology including stock type and age, Towers & Smith (1983) conservatively suggested provisional herbage Na concentrations required for deficient and adequate nutrition for pasture-fed animals for both sheep and cattle (Table 6). This information can now be extended to include dairy cows by taking into account the recent results of O'Connor et al. (2000) and McDonald et al. (2002).

The situation appears to be different in the United Kingdom. Chiy & Phillips (1991) reported milk fat responses to fertiliser Na applications on perennial ryegrass pastures (average concentration 0.29% Na), but direct Na supplementation of dairy cows had no effect. Some animal behavioural effects of Na, such as increased grazing time and preferential grazing, were also measured. Fertiliser Na also increased pasture production, and given that the site was K deficient, it is likely that these observed effects of fertiliser Na were due to Na substituting for K, alleviating K deficiency and consequently increasing the pasture quantity and quality. In this sense the experiment mimicked the results of McNaught & Karlovsky (1964). Cushnahan et al. (1996) reported no significant effects of fertiliser Na or Na supplementation on milk yield or herbage intake. In this instance, the untreated pasture had a Na concentration of 0.24% and all the animals received a supplement containing Na. In contrast, Phillips et al. (2000) conducted a series of experiments on predominantly ryegrass pasture with Na concentrations >0.30%. They reported both production (milk yield) and behavioural (grazing preference, increased intake) responses to fertiliser Na and suggested at least 0.40% Na for optimal production and animal health.

Table 5 Animal grazing trials in New Zealand examining the effect of sodium (Na) supplementation or fertiliser on animal production. DM, dry matter; –, no data.

Soil group	Animal type	Treatments	Control pasture concentration (% DM) %Na	%K	Liveweight	Comment	Reference
Pumice	Sheep (lambs)	Lucerne grazing ± Na drench	0.03	–	Response in liveweight and fleece weight		Joyce & Brunswick (1975)
Pumice	Sheep (lambs)	Lucerne grazing ± Na drench × ± Na spray to pasture	0.03	–	Response in liveweight and fleece weight	No effect of drench on sprayed pasture	As above
Pumice	Beef (weaners)	Lucerne feeding trial ± Na sprinkled on feed	0.03	–	Response in liveweight	No effect of Na on DM intake	As above
Pumice	Beef (yearlings)	As above	0.03	–	Response in liveweight	No effect on DM intake	As above
Pumice	Cows (dairy)	Pasture grazing ± Na drenching	0.06	–	Response in milk production		As above
Pumice	Cows (breeding)	NaCl fertiliser (200 kg/ha) to pasture	0.08-0.09	3.5–3.7	No response	NaCl increased incidence of hypomagnesaemia	Smith et al. (1983)
Pumice	Cattle (weaners)	NaCl fertiliser (200 kg/ha) to pasture	0.08-0.11	3.8–4.5	Liveweight response in 1 of 2 years	Response when pasture Na 0.08% but not at 0.11%	As above
Pumice	Cattle (weaners)	± NaCl fertiliser (200 kg/ha) × ± NaCl drench (50 g/week)	0.10	–	Response to Na fertiliser and drenching in absence of Na fertiliser		Towers et al. (1984)
Pumice	Sheep (ewes)	± Na supplement as salt lick × pasture allowance	0.07	–	Response at low level of allowance but only marginal response at high allowance		As above
Pumice	Cows (dairy)	± Na supplement	0.05	–	Milk production response		O'Connor et al. (2000)
Allophanic	Cows (dairy)	± Na supplement	0.10	–	No response		McDonald et al. (2002)

It is difficult to resolve these two sets of results except to suggest that there may be two distinct mechanisms by which fertiliser Na applications to temperate pastures may affect animal production. The first order effect, which occurs at low pasture Na concentrations (<0.10%) is to meet the animal's physiological requirement for Na. This is essentially what has been measured in the New Zealand experiments. Over and above this, secondary effects of Na fertiliser may occur on pastures, even though the initial Na concentration is >0.30%. These include possible effects of Na on the biochemical composition of pasture, which affect pasture intake and utilisation, and direct effects on animal metabolism, such as mammary gland health. Further research is required to test these possibilities.

Until further research is completed, it must be accepted that the critical minimum Na concentration for mixed pasture in New Zealand is 0.10%. Several factors will modify this requirement including lower than normal DM intakes, frequency of rainfall, proximity to the sea, and access to other sources of Na such as licks and drinking water. All of these factors will influence the amount of Na required from pasture to achieve optimal health and production.

Applying this estimate of the minimum Na requirement of 0.10% to the survey data collected by Smith & Middleton (1978), rather than the earlier recommendations from the National Research Council used by Smith & Middleton (1978), a more accurate assessment of the possible degree and extent of Na deficiency for animal production can be made. These modifications suggest that c. 20% of dairy farms in New Zealand may be Na deficient with respect to optimal dairy production and c. 5% deficient for optimal sheep production. This conclusion, however, must be treated cautiously. The pasture samples used by Smith & Middleton (1978) in their survey were largely collected for advisory purposes over the period 1952–75. The time of year when the samples were taken is not known, nor is the botanical composition of the samples. Both factors can affect the whole pasture Na composition as noted by Smith & Middleton (1978) (for examples of the seasonal × species effects on pasture Na concentrations see Edmeades et al. 1983 and O'Connor et al. 1989). Careful monitoring of pasture Na status is therefore required to accurately establish plant Na levels before a conclusion of Na deficiency can be reached with confidence.

Table 6 Sodium (Na) concentrations in mixed pasture required for deficiency and adequacy for different classes of animals (modified from Towers & Smith 1983, see text).

Animal class	Deficient (%Na)	Adequate (%Na)
Sheep		
lambs	0.04	0.07
maintenance	0.04	0.07
flushing	0.05	0.09
lactation	0.05	0.09
Cattle		
young stock	0.06	0.10
maintenance	0.06	0.10
lactation	0.09	0.12
Dairy cows		
lactation	0.10	0.12

DIAGNOSING Na DEFICIENCY

Symptoms of Na deficiency in pasture plants have not been recorded, possibly because the effects of Na are non-specific. Where yield responses to Na fertiliser in the presence of adequate K have been recorded in some natraphobes, such as beets, mangolds, and spinach, the soil Na concentrations are typically <0.05 me/100 g (MAF QT Na < 2). This probably sets the critical level for Na deficiency in plants. In the three trials reported by O'Connor et al. (1989), the soil Na levels were 5, 5, and 8 QT units for the pumice, allophane, and organic soils respectively, corresponding with mixed pasture Na concentrations of 0.07, 0.12, and 0.06%. This, together with field experience, suggests that where soil Na levels are <5 QT units, pasture Na concentrations should be regularly monitored to ensure that the pasture Na concentrations do not fall below the critical level of 0.10%.

Symptoms of Na deficiency in animals are also non-specific and include poor appetite, ill thrift, rough coat, and lustreless eyes. Na-deficient animals also lick wood, soil, and the sweat from other animals. The best diagnostic method at present for animals is the Na:K ratio in the parotid saliva (Towers & Smith 1983). The procedure for collecting these samples is, however, time consuming and requires veterinary supervision. Summarising available New Zealand and overseas trials, Towers & Smith (1983) reported that the production responses to Na supplementation have been measured in both beef cattle and lactating cows with pre-supplementation Na:K ratios of <5:1. In comparison, animals either supplemented with Na or grazing pasture with adequate Na, had Na:K ratios of between 10:1 and 22:1 (sheep) or 20:1 and 28:1 (cattle). In the more recent work reported by O'Connor et al. (2000) the control animals had Na:K ratios of 6.7:1 and the treated animals 16.8:1.

Turner (1981) suggested, on the basis of 12 samples, that the incidence of bloat in ruminants may be related to the Na:K ratio in the pasture, postulating that a ratio Na:K > 1:20 may exacerbate bloat. Carruthers et al. (1987, 1988) concluded, based on survey results and animal feeding trials, that the incidence and severity of bloat was not related to soil or plant Na, K or Na:K levels. Furthermore, they sampled 91 herds (50% low bloat incidence and 50% high bloat incidence) and measured the saliva Na:K ratio and found that there was no difference between the low and high incidence herds with respect to the Na:K ratio.

CORRECTION OF Na DEFICIENCY

When Na deficiency has been confirmed or is suspected, there are a number of remedial strategies. The details are given by Towers & Smith (1983) and include: drenching with NaCl, salt licks, water trough treatment and the application of fertiliser Na. Based on information then available, they suggested applications of fertiliser Na of 125–150 kg NaCl/ha to raise pasture Na concentration. But subsequent results (O'Connor et al. 1989) suggest that inputs of 100 kg NaCl/ha (40 kg Na/ha) are sufficient to increase pasture concentrations above the critical level for dairy animals of 0.10%, even on soils with initially low soil Na concentrations (MAF QT < 5).

Note that fertiliser Na cannot be effective on pastures dominated by natrophobes such as lucerne, kikuyu or paspalum. Sodium supplementation is essential under these circumstances or, as Sherrell (1984) suggested, a natrophile should be planted with the natrophobe—in his specific instance phalaris was used as a companion grass with lucerne. This has worked well in the field in Northland (M. B. O'Connor unpubl. data) where ryegrass (a natrophile) is introduced into kikuyu swards (a natrophobe) as a companion species.

It is possible to substitute fertiliser Na for fertiliser K to some extent on pastures containing predominantly natrophilic species, on soils that are K deficient. However, given current prices it would not be economic to use fertiliser Na rather than normal fertiliser K inputs.

CONCLUSIONS

Much progress has been made in the last decade on defining the Na requirements of pasture-fed animals and the management of soil and pasture Na. Under New Zealand conditions, the critical pasture Na level for optimal animal production in lactating dairy cows is between 0.05 and 0.10% DM. Lower concentrations are sufficient for other classes of animals. Further research is, however, required to determine under New Zealand conditions whether Na applications to pastures with Na concentrations above this critical level affect pasture feed intake and animal health.

Until this further research is completed the practical goal to optimise production should be to maintain pasture Na concentrations at >0.10% (soil QT Na > 5) by regular monitoring and the application of Na fertiliser (100 kg NaCl/ha) or by supplementing the diet with the addition of Na to the drinking water or directly by drenching.

ACKNOWLEDGMENTS

The project was funded by the New Zealand Fertiliser Manufacturers Research Association.

REFERENCES

Agricultural Research Council 1965: Requirement for major mineral elements: sodium and chlorine. *In*: The nutrient requirements of farm livestock. No 2. Ruminants. Agricultural Research Council, London. Pp. 71–77.

Carruthers, V. R.; O'Connor, M. B.; Feyter, C.; Upsdell, M. P.; Ledgard, S. F. 1987: Results from the Ruakura bloat survey. *Proceedings of the Ruakura Farmers Conference 39*: 44–46.

Carruthers, V. R.; Norton, D. H.; O'Connor, M. B. 1988: The incidence of bloat on pasture differing in K:Na ratio. *Proceedings of the New Zealand Grassland Association 49*: 169–170.

Chiy, C. P.; Phillips, C. J. C. 1991: The effects of sodium chloride application to pasture, or its direct supplementation, on dairy cow production and grazing preference. *Grass and Forage Science 46*: 325–331.

Cornforth, I. S.; Sinclair, A. G. 1984: Fertiliser recommendations for pastures and crops in New Zealand. 2nd ed. MAF, Wellington.

Cushnahan, A.; Gordon, F. J.; Bailey, J. S.; Mayne, C. S. 1996: A note on the effect of sodium fertilisation of pasture on the performance of lactating dairy cows. *Irish Journal of Agriculture and Food Science 35*: 43–47.

Edmeades, D. C. 1982: Effects of lime on effective cation exchange capacity and exchangeable cation on a range of New Zealand soils. *New Zealand Journal of Agricultural Research 25*: 27–33.

Edmeades, D. C.; Smart, C. E.; Wheeler, D. M. 1983: Effects of lime on the chemical composition of ryegrass and white clover grown on a yellow brown loam. *New Zealand Journal of Agricultural Research 26*: 473–481.

Edmeades, D. C.; Wheeler, D. M.; Clinton, O. E. 1985: The chemical composition and ionic strength of soil solutions from New Zealand topsoils. *Australian Journal of Soil Research 23*: 151–165.

Joyce, J. P.; Brunswick, L. C. F. 1975: Sodium supplementation of sheep and cattle fed lucerne. *New Zealand Journal of Experimental Agriculture 3*: 299–304.

Ledgard, S. F.; Roach, C.; Sprosen, M.; Rajendram, G. 2001: Cation balances on dairy farms and implications: North Island. News you can use. Hamilton, New Zealand, Celentis Analytical.

McDonald, K. A.; Lile, J. A.; Lancaster, J. A. S.; Coulter, M.; O'Connor, M. B. 2002: Salt supplementation of lactating dairy cows. *New Zealand Society of Animal Production 62*: 236–239.

McNaught, K. J.; Karlovsky, J. 1964: Sodium chloride responses in pasture on a potassium deficient soil. *New Zealand Journal of Agricultural Research 7*: 386–404.

Marschner, H. 1971: Why can sodium replace potassium in plants. 8th Colloquia International Potash Institute, Uppsala.

Marschner, H. 1995: The mineral nutrition of higher plants. 2nd ed. London, Academic Press. fig. 10, P. 410.

Metson, A. J. 1962: New Zealand single factor maps. Wellington, DSIR.

Monaghan, R.; Paton, J.; Smith, C. 2001: Cation balances on dairy farms and implications: South Island. News you can use. Hamilton, New Zealand, Celentis Analytical.

New Zealand Soil Bureau 1968: Soils of New Zealand. Parts 1, 2, 3. *New Zealand Soil Bureau Bulletin 26*.

O'Connor, M. B.; Addison, B.; Miller, A. D. 1989: The effects of topdressing dairy pastures in the Waikato with sodium chloride. *Proceedings of the New Zealand Grasslands Association 50*: 83–87.

O'Connor, M. B.; Hawke, M. F.; Waller, J. E.; Rotheram, J. R.; Coulter, S. F. 2000: Salt supplementation of dairy cows. *Proceedings of the New Zealand Grasslands Association 62*: 49–53.

Phillips, C. J. C.; Chiy, P. C.; Arney, D. R.; Kart, O. 2000: Effects of sodium fertilizers and supplements on milk production and mammary gland health. *Journal of Dairy Research 67*: 1–12.

Sherrell, C. G. 1984: Sodium concentration in lucerne, phalaris, and a mixture of the two species. *New Zealand Journal of Agricultural Research 27*: 157–160.

Smith, G. S.; Middleton, K. R. 1978: Sodium and potassium content of topdressed pastures in New Zealand in relation to plant and animal nutrition. *New Zealand Journal of Experimental Agriculture 6*: 217–225.

Smith, G. S.; Middleton, K. R.; Edmonds, A. S. 1978: A classification of pasture and fodder plants according to their ability to translocate sodium from their roots into aerial parts. *New Zealand Journal of Experimental Agriculture 6*: 183–188.

Smith, G. S.; Young, P. W.; O'Connor, M. B. 1983: Some effects of topdressing pasture with sodium chloride on plant and animal nutrition. *Proceedings of the New Zealand Grasslands Association 44*: 179–185.

Towers, N. R.; Smith, G. S. 1983: Sodium. *In*: The mineral requirements of grazing animals. Grace, N. D. *ed. New Zealand Society of Animal Production. Occasional Publication No. 9.*

Towers, N. R.; Young, P. W.; Smeaton, D. C. 1984: Sodium requirements of grazing livestock. *Proceedings of the New Zealand Society of Animal Production 44*: 155–157.

Turner, M. A. 1981: Dietary potassium sodium imbalance as a factor in the aetiology of primary tympany in dairy cows. Vetinerary Research Communication.