A comparison under grazing of pasture production, pasture N content and soil mineral N levels between granular urea and ONE*system*® on two contrasting dairy farms in New Zealand

B.F. QUIN [1], A.G. GILLINGHAM [2], D. BAIRD [3], S. SPILSBURY [4] and M. GRAY [5]
[1]*Quin Environmentals (NZ) Ltd, PO Box 125-122, Auckland 1740, New Zealand*
[2]*Agricultural Research Consultant, 92 Waicola Drive, Palmerston North 4471, New Zealand*
[3] *VSN NZ Ltd, 8 Mariposa Crescent, Christchurch 8025, New Zealand*
[4]*FOO Technologies, PO Box 892, Newry, Victoria 3859, Australia*
[5]*Maurice Gray & Associates Ltd, 1 Aotea Crescent, Havelock North, New Zealand*
bert.quin@gmail.com

Abstract
Field trials under grazing on two contrasting dairy farms in mid-Canterbury (Site C) on a stony silt loam under irrigation, and in rain-fed central Waikato (Site W) on a volcanic ash-derived soil, compared standard granular urea (4–5 mm diameter granules) with ONE*system*®. This uses prilled urea (0.8–2.8 mm diameter prills), passed through a fine water spray (50 litres/ha) that contains the urease inhibitor nbpt (2 gm nbpt/kg N) during application. A nil N control and three rates of each fertiliser were applied to 12 × 25 m plots on four occasions after rotational grazing during spring/early summer 2014. ONE*system*® resulted in extra dry matter (EDM) to N applied compared with granular urea at Site C. At Site W, the initial advantage to ONEsystem® in Period 1 (early spring) was not maintained.

To produce EDM of 1250 (±750) kg/ha required 120 and 126 kg N/ha as granular urea at Sites C and W, respectively (giving EDM factors of 10.4 and 9.9 (± 2) kgDM/ kgN applied respectively). This compares with 50 and 74 kg N/ha required with ONE*system*® for higher EDM factors of 24 and 17 (± 5) kg DM/ kg N.

Pasture N concentrations were higher at Site C following ONEsystem® application, and total N uptake was increased 3-fold compared to granular urea. At Site W, increases in EDM with ONE*system*® only occurred in the first period.

The results of this study have implications for both the economic and environmental efficiency of fertiliser urea use on grazed pastures.

Keywords: ONE*system*®, prilled urea, nbpt, granular urea, N efficiency, pasture, N uptake

Introduction
Granular urea is the most widely used nitrogen (N) fertiliser in New Zealand, with recent estimates of 600 000 to 750 000 tonnes applied annually (Argus FMB 2014). Most of the increase in the last 15 years is attributed to increasing use on dairy farms, with more than 400 kg N/ha applied annually on some farms (Glassey *et al.* 2013).

Many dairy farmers choose to spread urea themselves, rather than use a contractor, to ensure that it is applied at the best time to optimise pasture growth, generally 1 to 3 days post-grazing.

Granular urea has been demonstrated internationally to be an inefficient source of fertiliser N when surface applied, with significant losses via volatilisation (ammonia), denitrification (nitrous oxide and N_2) and leaching (nitrate-N); (Chien *et al.* 2009; Freney 2011). Cornforth (1998) concluded that an average of 15–20% of urea-N is volatilised in New Zealand conditions. More recently, Bishop & Manning (2011) reviewed ammonia volatilisation losses in New Zealand and elsewhere, and reported losses of 4.2–33.3% in New Zealand, a similar range to that found in other countries. They concluded that losses of less than 10% would only occur on highly acid soils with pH of 5.3 or less and with high cation exchange capacity (> 25 meq/litre). Few dairy farms in New Zealand operate at soil pH levels less than 5.5, the few exceptions being on the West Coast of the South Island under extremely high rainfall (>2500 mm per year).

The response of pasture growth to fertiliser N is variously referred to using terms such as "pasture N response", "pasture N efficiency" or "nitrogen use efficiency" (NUE). All are subject to some misinterpretation or differences in intended meaning. The authors here recommend the terms "extra dry matter" (EDM) for the absolute increase in kg DM/ha compared to the nil N control, and "EDM factor" for the EDM/kg N, for their clarity. An EDM factor of 10 is frequently used as the default value for urea by farmers and farm advisors in New Zealand (Anon 2008). This represents only 30–35% recovery of urea N for pasture containing 3.0–3.5% N, somewhat lower than can be ascribed to ammonia volatilisation losses alone; an EDM factor of 7 is used by DairyNZ in their advice to farmers for autumn use of granular urea (Anon 2008).

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online)

Even lower EDM factors (of 3 or below) have been reported (in non-reviewed conference proceedings) to occur from January to August (Roberts & Thomson 1989). Such low EDM factors, and the implied low N recoveries, are sometimes partly attributed to incorporation of urea N into soil organic N (Ledgard et al. 1999). However, there is little if any evidence of net accumulation in soil organic N levels on established dairy farms, as compared with soil on farms recently converted to dairying from forestry, or extensive sheep and beef farming. Any incorporation of fertiliser N into soil organic matter on established dairy farms is most likely to be a short-term part of the soil N cycling process.

SustaiN® is granular urea treated with a urease inhibitor (nbpt). Watson et al. (2009) summarised two decades of published scientific research which demonstrated the effectiveness of nbpt in Ireland in both reducing ammonia volatilisation from granular urea and increasing pasture response. These findings were supported by field studies in New Zealand (Blennerhassett et al. 2006). Zaman et al. (2008) demonstrated the additional, indirect benefit of nbpt in reducing nitrate leaching from fertiliser urea, as well as reductions in ammonia volatilisation and nitrous oxide emission. EDM factors with SustaiN®, averaged over three rates of N, were +24%, -3%, and +79% (+33% overall) higher than granular urea in spring, summer and autumn respectively (Martin et al. 2008). The authors noted that the summer trial application was preceded and followed by sufficient rainfall to ensure movement of urea below the soil surface, thereby minimising volatilisation losses. Stafford et al. (2008) demonstrated that in conditions selected on the basis of being not conducive to ammonia volatilisation (late winter/early spring), improvements in N efficiency with SustaiN® compared to granular urea were statistically insignificant in 8 out of 11 such selected sites. These results and those of Zaman et al. (2008) were used by Ballance Agri-Nutrients Ltd to develop the advisory recommendation for farmers, viz "Use SustaiN® instead of urea unless 5–10 mm of rain is guaranteed within 8 hours of applying N" (Ballance Agri-Nutrients 2015).

Further progress in N efficiency requires focus on more avenues for improvement than on reducing ammonia volatilisation. Consequently, this paper presents results from three trials conducted under grazed dairy farming, in which standard, commercial granular urea (4–5 mm granule diameter, mean diameter 4.7 mm) was compared with a new process known as ONE*system*®, developed since early 2013. ONE*system*® uses standard, commercial imported prilled urea (international standard 0.8–2.8 mm prill size range, mean 1.5 mm), wetted during spreading with a fine water spray (50 litres/ha) containing 2 gm nbpt/kg applied N (0.2%).

Materials and methods

Trial design

The experiments were conducted on an irrigated dairy farm near Hororata in mid-Canterbury South Island (Site C; location S 43° 34′ 39″, E 171° 56′ 36″), and on a rain-fed dairy farm near Kiwitahi in central Waikato (Site W; location S 37° 45′ 59″, E 175° 34′ 45″). Soils were a Lismore stony silt loam, a Yellow Grey Earth classified as an Ustrechrept under USDA taxonomy (Site C), and a granular, moderately free-draining allophanic Yellow Brown Loam or Humult (Site W). Both pastures were ryegrass dominant, with <1% and 7% clover present in Sites C and W respectively (Table 1), probably reflecting previous N inputs of over 150 kg N/ha annually. Plant densities were measured at both sites, by averaging the number of individual plants in random 0.25 m^2 quadrats on the control (nil N) plots at both sites. Densities averaged 420/m^2 and 440/m^2 at Sites C and W respectively. Soil tests indicated nutrient levels were quite adequate for vigorous ryegrass growth on the respective soil types (Table 1). No fertiliser of any type was applied to either site in the three months preceding commencement.

The treatments included a nil N control, three rates of granular urea and three rates of the ONEsystem® processed prilled urea (Table 1). Mean particle diameters were 4.7 mm and 1.5 mm for granules and prills respectively, giving a calculated average distribution density of 45 and 450 particles/m^2 respectively at an application rate of 30 kg N/ha. The higher distribution density is referred to as "better coverage" in the fertiliser industry. Earlier experiments

Table 1 *Soil characteristics, herbage composition and N treatments at Canterbury (Site C) and Waikato (Site W) experiments.*

	Soil 'Quick' test					Pasture spp. (%)				+N rates (kg N/ha per application)	
	pH	P	K	S	CEC	rye	clvr	poa	wds	granular urea	ONE*system*®
Site C	5.6	26	4	11	11	99	0.5	0.1	0.5	14.1, 28.2, 42.3	14.0, 28.0, 43.0
Site W	6.6	42	12	11	32*	68	7	22	3	27.4, 54.8, 82.2	18.3, 36.6, 54.9

*note high effective CEC at Site W due to pH

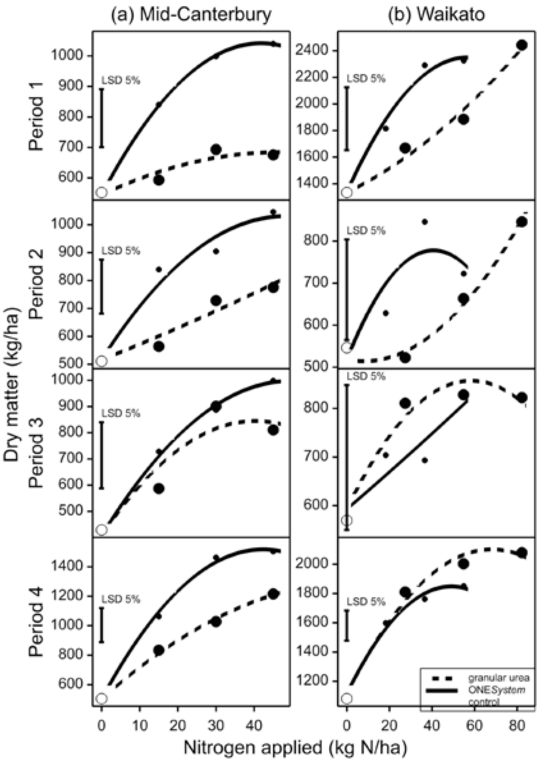

Figure 1 Pasture extra dry matter (EDM) at Canterbury (Site C) and Waikato (Site W) experiments with increasing rates of N as granular urea or ONE*system*® on four occasions. The LSD at the 5% level between means is shown as a vertical bar.

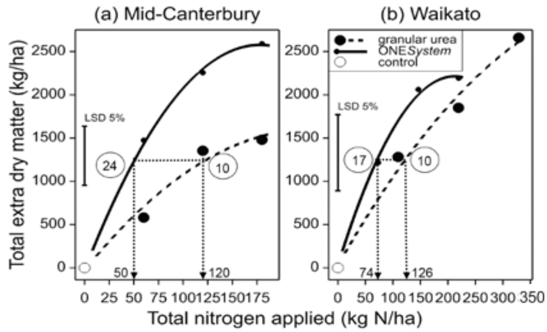

Figure 2 Total pasture extra dry matter (EDM) at Canterbury (Figure 2a, Site C) and Waikato (Figure 2b, Site W) experiments from increasing rates of nitrogen applied as either granular urea (dashed lines) or as ONE*system*® (solid lines). The dotted lines with associated numbers give the predicted total application of N for granular urea and ONEsystem® to achieve EDM of 1250 kg/ha at either site. The numbers circled are the respective EDM factors (kg extra DM/ kg N applied). The least significant difference at the 5% level between means is shown as a bar labelled LSD 5%.

with similar products, both in Gippsland, Victoria, and in the Waikato, New Zealand, showed that fine urea supplied without adequate water spray incorporating nbpt resulted in mild to severe leaf scorch, except where the leaves were already damp due to dew, rainfall or irrigation (S. Spilsbury pers.comm.; B. F. Quin unpublished). The addition of both spray and nbpt was therefore considered to be a sensible risk-mitigation practice until studies have been undertaken in a wider range of conditions.

Each treatment had four replicates. Plot size was 12 × 25 m, chosen to encompass spreading of urea as typically undertaken by farmers. These plots included obvious urine and dung-response patches of varying ages (40–60 per plot), which were particularly visible at Site C. All pasture dry matter (DM) data reported here are from random in-plot measurements only.

Three rates of each fertiliser were applied by an Agrispred SNGN 460 spreader, immediately after each of four grazing events during spring/early summer 2014. These rates covered the range of rates commonly used by New Zealand dairy farmers (25–50 kg N/ha), and were expected to define the N response curve. Application rates applied were checked by weighing on sheets of soft material to minimise bounce. At site W, a malfunction with the granular urea rate at the first application meant that higher rates than intended were applied (Table 1). To avoid complications with the response curve, these rates were repeated at subsequent applications of granular urea at this site (Table 1). The intended rates of ONEsystem® were applied. The physical fate of prills and granules that landed on pasture leaves was observed on some occasions.

Pasture yields before and after each grazing event were measured on individual plots using a rising plate-meter (30 readings per plot), which was calibrated against weighed DM quadrats (Table 3).

Table 3 Regressions of weighed pasture dry matter against rising plate measurements at Canterbury (Site C) and Waikato (Site W) experiments, and overall.

Site C	Actual DM (kg/ha) = 0.791 × plate reading - 279	R^2= 0.841
Site W	Actual DM (kg/ha) = 0.746 × plate reading - 249	R^2 = 0.858
Overall	Actual DM (kg/ha) = 0.789 × plate reading – 281	R^2= 0.820

The calibration combining the data from both sites over the trial durations were applied to derive pasture cover before and after grazing. Only the former are reported here (Figures 1 and 2). Topsoil (0–75mm) samples were taken on four occasions (20 October, 10 November, 2 and 22 December), from inter-urine areas within each plot, immediately before the next fertiliser N application, for ammonium-N and nitrate-N analysis, and the results averaged for the four samplings (Figure 4).

An additional, single application, 8-week duration trial commenced at Site C in early summer (11 November). This trial (Site C2), which ran for two grazing rotations, was designed to help define the relative importance of the components of ONEsystem®. Treatments were dry prills vs dry granules, wetted prills vs wetted granules, and wetted prills + nbpt (ONE*system*®) vs wetted granules+nbpt (Table 4). There were 4 replicates of each treatment, using a randomised block design. All prilled urea treatments were applied at 28.0 kg N/ha, and all granular urea treatments at 28.2 kg N/ha.

Statistical analysis

A randomised block design with four replicates was used to statistically analyse the seven treatments (control plus three levels of application for granules and prills) at both Sites C and W. The data were analysed using analysis of variance in GenStat. The least significant differences (LSDs) at the 5% level were calculated and these are presented in Figures 1-6. Separate quadratic curves were fitted to the granules and prills application rates using regression in GenStat. A common intercept was used, as both series contained the control treatment. As treatments are structured and there are only a few comparisons of interest, adjustment for multiple comparisons was not used. Statistical significant differences and LSDs between the effects of granules vs prills on pasture production are noted in the captions of relevant Figures.

For the additional trial (Site C2), data were analysed using analysis of variance in Genstat. (Table 4). Duncan's Multiple Range Test lettering was used to show treatments that were significantly different (P<0.05) from one another.

Weather data and irrigation

Rainfall and soil temperature data around the fertiliser application dates for the trials are given in Table 2. For

Table 2 Daily rainfalls (mm) and maximum air temperatures (°C), all rounded, in days before and after N application dates, and average wind and maximum gusts (km/hr) on days of application, at Site C (mid-Canterbury) and Site W (Waikato).

Dates	(rainfall days prior) **on** (rainfall days after)													max temp °C							av. wind*
day/mth	6	5	4	3	2	1	**0**	1	2	3	4	5	6	3	2	1	**0**	1	2	3	(max. gusts)
Ca **24/9**	0	0	10	0	0	0	**0**	0	0	6	0	0	0	8	4	8	**14**	12	15	10	**4 (24)**
Cb **21/10**	0	8	1	5	0	5	**0**	0	0	0	0	0	1	11	9	14	**9**	12	13	9	**5 (18)**
Cc **11/11**	0	0	0	0	0	0	**0**	0	0	0	0	0	0	12	14	15	**18**	10	11	12	**6 (30)**
Cd **3/12**	0	4	0	8	2	0	**0**	0	4	0	0	0	2	14	7	11	**13**	22	12	15	**11 (26)**
Wa **17/9**	11	4	1	2	3	0	**11**	5	14	8	1	0	0	13	11	13	**12**	11	13	11	**8 (27)**
Wb **14/10**	0	1	0	0	0	0	**0**	0	0	13	0	0	0	11	12	12	**14**	13	14	14	**1 (20)**
Wc **21/11**	0	19	0	0	0	0	**0**	0	0	0	0	7	2	15	14	14	**15**	17	17	15	**8 (24)**
Wd **9/12**	0	0	0	0	1	1	**9**	0	0	4	2	0	0	17	17	20	**17**	18	18	16	**6 (16)**

Figures in **bold** are for days of fertiliser N application * km/hr

Table 4 Canterbury Site C2. Pasture yield (kg DM/ha) obtained with a nil N control and single applications of N (28 kg N/ha) of dry, wetted and wetted+nbpt versions of granular and prilled urea. Extra dry matter (EDM) factors are in brackets.

	Control (nil N)	**dry fertiliser N**	**N +water**	**N + water + nbpt**
Granular urea	1727[a]	2016[ab]	1780[ab]	2121[bc]
		(9.6)	(1.8)	(13.1)
Prilled urea	1727[a]	2344[cd]	2579[d]	2432[d]
		(20.6)	(28.4)	(23.5)

LSD 5%: 297. Significance : urea*** ; urea form (granular/prilled)***; urea form × method*
Duncan's Multiple Range Test: Treatments results that are not followed by the same letter differ (P<0.05) from one another.

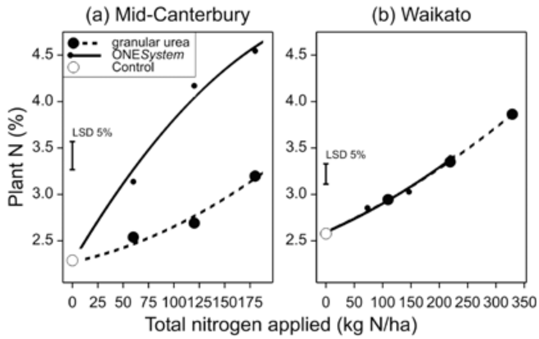

Figure 3 Average plant nitrogen percentage over four periods prior to grazing events at the Canterbury (Fig. 3a, Site C) and Waikato (Fig. 3b, Site W) experiments from increasing rates of N applied as either granules or ONE*system*®.

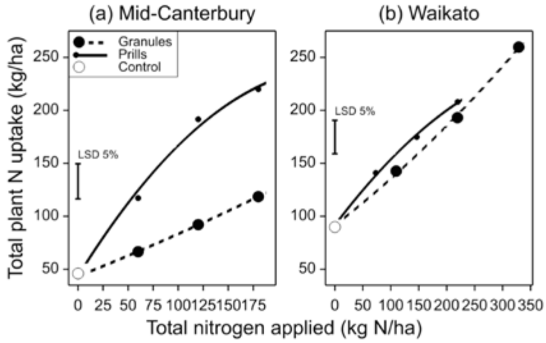

Figure 4 Average plant nitrogen uptake (Kg N/ha) over four periods prior to grazing events at the Canterbury (Site C, Fig. 4a) and Waikato (Site W, Fig. 4b) experiments from increasing rates of N applied as either granules or ONE*system*®.

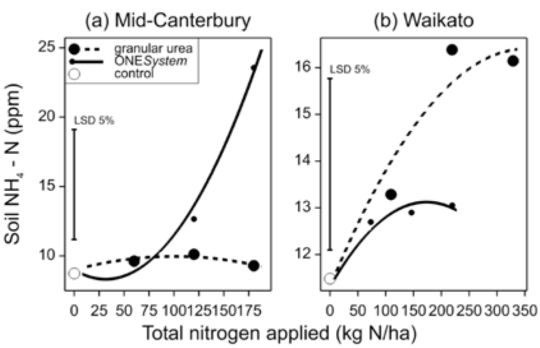

Figure 5 Soil ammonium-N (ppm) averaged over four applications at the Canterbury (Fig. 5a, Site C) and Waikato (Fig. 5b, Site W) experiments from increasing rates of N applied as either granules or ONE*system*®.

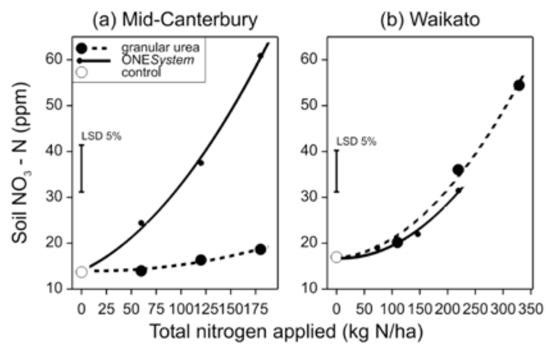

Figure 6 Soil nitrate-N levels (ppm) averaged over four applications at the Canterbury (Fig. 6a, Site C) and Waikato (Fig. 6b, Site W) experiments from increasing rates of N applied as either granules or ONE*system*®.

Site C, NIWA's Horarata West station was used for rainfall data, with the Lincoln Broadfields site (NIWA and Plant & Food Research) providing temperature and wind data. The weather at Site C was unusually dry during the trial period. The farmer moved a "Rotorainer" irrigation system around the farm on an approximately weekly rotation, set to deliver up to 20 mm per irrigation. This ensured that any drainage (and therefore nitrate leaching) was never excessive. The soil was observed during the four soil sampling occasions to have dropped below optimum moisture levels on some occasions, but no wilting of pasture was observed. The rotation was as per normal farm practice, except that the farmer delayed irrigation of the trial paddock by one day on the one occasion when irrigation would otherwise have occurred on the same day as fertiliser application.

For Site W, all data were available from NIWA's Toenepi site. There were more rainfall events at Site W than at Site C. Site W also maintained good pasture growth throughout the trial. The soil was observed to be gradually drying out during the last two soil sampling occasions, but as at Site C, no wilting of pasture was observed. As with Site C, little drainage and therefore leaching of nitrate below the root zone was assumed to have taken place during the trial.

Results

Physical fate of applied fertiliser particles

Prills and granules naturally landed on both plant leaves and on bare ground. The majority of granules of urea that landed on foliage were observed to roll off the leaves during application, even when applied to wet pasture, and reach the soil surface. The exceptions occurred generally when granules became trapped in a leaf-stem juncture. These had invariably disappeared the following day, presumably due to dissolution of the highly hygroscopic product overnight. By comparison, many of the much lighter wetted prills that did not directly land on the soil surface adhered to the leaves. Some of these dried out and became dislodged by wind or leaf movement; others were observed to gradually dissolve on the leaf surface over a period of hours as has been observed in field trials with similar products in Gippsland, Victoria, Australia and in the Waikato, New Zealand (S Spilsbury, pers. comm.; B.F. Quin unpublished). The lower addition of anti-caking agent to commercially manufactured prills compared to granular urea would have assisted dissolution of the former (S.Harold, pers.comm.).

Dry matter yields

At Site C, EDM was greater with ONE*system*® ($P<0.05$) than with granular urea on three of the four individual growth periods (Figure 1(a); $P<0.05$), and overall when N application rate exceeded 20 kg N/ha (Figure 2(a); $P<0.05$). Plots treated with ONE*system*® could be visibly differentiated with the naked eye. Urine patches from previous grazings were far less discernible where ONE*system*® had been applied than in the nil-N control or granular urea plots, indicating that the strong pasture responses occurring in the plot inter-urine areas reduced the percentage difference in DM between urine-affected and inter-urine areas. Over the trial duration, four applications of 30 kg N/ha (a total of 120 kg N/ha) as ONE*system*® produced 2320 kg/ha EDM, compared to only 1250 kg/ha EDM with granular urea (Figure 2(a)).

At site W, EDM with ONE*system*® was greater ($P<0.05$) than with granular urea for the first grazing rotation at the intermediate rates of N application (25–40 kg N/ha), but not subsequently, or at all rates of application, at this level of significance (Figure 1(b)).

Over the trial duration, a total of 120 kg N/ha as ONEsystem® produced 1770 kg/ha EDM, compared to 1200 kg/ha EDM with granular urea (Figure 2(b)). This difference achieved significance at the 10% level.

N uptake by pasture

At Site C, herbage N levels in control plots averaged 2.25% (Figure 3(a)). ONE*system*® application resulted in significantly greater pasture N concentrations of 3.2–4.6% N at N rates of more than 25 kg N/application (Figure 3(a)), and consequently greatly increased N uptake (Figure 4(a)). At Site W, trial-average pasture N concentrations and uptake increased almost linearly with N application rate for the two fertiliser types Figures 3(b) and 4(b). There were no significant differences in these effects between forms of N.

Soil mineral N levels

At Site C, levels of soil ammonium-N increased ($P<0.05$) with total N application over the trial duration of approximately 150 kg N/ha as ONE*system*® (Figure 5(a)); soil nitrate-N increased ($P<0.05$) with total N application over approximately 75 kg N/ha (Figure 6(a)). There were no significant increases in either form of soil N with granular urea at this site (Figures 5(a) and 6(a)).

At site W, there were statistically significant increases in ammonium-N with granular urea (Figure 5(b)) and in nitrate-N with both ONE*system*® and granular urea (Figure 6(b). There were no significant differences between the two types of fertiliser at this site with either soil ammonium-N or nitrate-N.

Site C2 - Coverage, water-spray and nbpt contributions to EDM

The fertiliser treatments were applied to this single application, 8-week duration trial after midday on 11 November. This day was warmer (max. 18°C) by 3 to 8°C than the preceding and following 3 days (Table 2). No rainfall fell over these days (Table 2), but morning dews were observed. With granular urea, only N+water and N+water+nbpt increased DM compared to the nil N control (Table 4). Dry prills produced higher DM ($P<0.05$) than dry granules and granules + water. The addition of water or water+nbpt to prills did not produce significantly greater yields than dry prills, but only prills+water and prills+water+nbpt produced higher ($P<0.05$) DM response than granules+water+nbpt (Table 4). The average EDM factor for all forms of prilled urea was higher ($P<0.05$) than that for all forms of granules averaged (24.2 *vs* 8.2, or 2.9 times).

Discussion

Mid-Canterbury (Site C)

On this irrigated site, four applications of 30 kg N/ha as granular urea (a total of 120 kg N/ha) gave EDM of 1250 kg DM/ha over the trial duration, an EDM factor of 10.4 kg DM/kg N applied. The same EDM required a total of 50 kg N/ha (i.e. four applications of 12.5 kg N/ha) using ONE*system*®, giving an EDM factor of 24, or 2.4 times higher than from granular urea (Figure 2).

Higher plant N concentrations ($P<0.05$) with ONE*system*® than from granule application at each rate of N application (Figure 3(a)) resulted in higher N recovery (Figure 4(a)). Estimated simplistically from plant N uptake, fertiliser N recovery ranged from 95 to 122% for ONE*system*® at this site. Recoveries of highly efficient fertiliser N exceeding 100% when calculated this way are not unknown. Hawkesford (2014) attributed this to fertiliser-stimulated roots scavenging more efficiently for soil mineral N and other nutrients. The high pasture N concentrations achieved with ONE*system*® in this trial have implications for increased urine-N loadings at the subsequent grazing, and it is therefore suggested that N applications as

ONE*system*® should not exceed 15–20 kg N/ha in the soil and climatic conditions similar to those at Site C.

Given the very large advantage to prilled urea in its various forms to granular urea at Sites C and C2, it is important to consider the possible factors responsible. As farm irrigation rotations at Site C were designed to avoid the soil water-holding capacity being exceeded, and no extreme rainfall events took place (Table 2), it is likely that nitrate leaching was not a major form of fertiliser N loss. The more even coverage, reduction in ammonia volatilisation, and a degree of foliar uptake are proposed as the main reasons for the superiority of the forms of prilled urea over granular urea at this site. These advantages are closely interlinked. With granular urea, the low distribution density of granules provides uneven distribution of fertiliser N to the 400-plus plants/m^2 and the pH of the soil solution surrounding each granule increases to 8.2 (Watson *et al.* 2009). At this level of soil pH, ammonia volatilisation is greatly enhanced (Bishop & Manning 2011). With prills however, those that rolled off the leaf surface and reached the soil could each have released an order of magnitude less N into the surrounding soil, meaning that the maximum localised soil pH could be approximately a full pH unit lower than with granules. Some of the urea from prills that dissolved on the leaf could have been taken up directly through the leaves, especially in the presence of nbpt (Dewar *et al.* 2010).

The combination of these effects explain both why prilled urea was effective, and granular urea inefficient, at Sites C and C2. The combination of the effects, and the reasonably efficient irrigation programme, make it very likely that ammonia volatilisation was the greatest N loss mechanism from granular urea at Site 2, reducing the recovery of applied N to 34–40% based on plant N uptake (from Figure 4(a)). At Site 2, over the period of the trial, the addition of water spray and nbpt did not add significantly to the effectiveness of either dry granular or dry prilled urea (Table 4). However it should be noted that granular urea gave an increase (P<0.05) in DM over the nil N control only when treated with water+nbpt (equivalent as a product to "wetted SustaiN®"), and prilled urea exceeded this treatment (P<0.05) only when treated with water or water+nbpt (ONE*system*®).

The soil nitrate-N and ammonium-N remaining in the surface soil at Site C after successive applications of the two higher rates of N applied as ONE*system*® (Figures 5(a) and 6(a)) would be expected to result in higher residual pasture growth, but with a risk of nitrate leaching if a heavy rainfall event occurred. For this reason as well, individual applications of no more than 15–20 kg N/ha per rotation as ONE*system*® are considered to be optimum under this soil type and irrigation. Furthermore, it could be expected that increasingly warm conditions over late spring, summer and early autumn would increase the risk-mitigation benefits of incorporating nbpt into a water spray applied with the prilled urea; both in terms of avoiding leaf scorch and increasing EDM factors.

Central Waikato (Site W)

For the first period, ONE*system*® produced more (P<0.05) DM than granular urea over the 25–40 kg N/ha range of fertiliser N application. Improved coverage, and with it more efficient plant uptake of fertiliser N, was assumed to be the most important factor during this first period of the trial at Site W.

The key question that then arises is why the advantage to ONE*system*® failed to show a continuing advantage as it had at Site C. This is particularly so given the higher pH (6.6) at Site W, as there is known to be a relationship between ammonia volatilisation from granular urea and pH when data from a very wide range of soil pH (4–8) is compared (Watson 2000; Bishop & Manning 2011). However, Dancer et al. (1973) found no differences over the narrower pH range investigated of 4.7–6.6. Also, the soil at Site W is known to have a high natural pH of 6.1–6.3 (Waikato Region Soil Maps 2015), but it also has a very high effective CEC (32 meq/litre, Table 1), the latter being one of the most important factors in reducing ammonia volatilisation (Bishop & Manning 2011). The combination of this, the 11 mm rainfall on the day of first N application and 27 mm over the following 3 days, and the 9 mm rainfall on the day of the last N application, would have minimised the risk of ammonia volatilisation from granular urea during the trial (Martin *et al.* 2008). In addition, the accumulation of ammonium-N with granular N at this site suggests that soil Nitrosomanas activity may have been insufficient to quickly nitrify the high levels of ammonium-N generated around individual fertiliser particles. Delayed nitrification is likely to have produced a high supply of nitrate-N in the latter stages of the trial (Figure 6(b)), again diminishing the advantage of ONE*system*®. Finally, the soil at Site W is described (Waikato Region Soil Maps 2015) as having imperfect drainage, which would have further reduced the advantage of ONE*system*® compared to granular urea by reducing nitrate leaching at this site. Fertiliser N recovery with granular urea, calculated from the increases in plant N content, were between 47 and 54% for all rates of N, with no effect of N rate, approximately 50% higher than the range of 30–35% calculated for Site C.

As far as the performance of ONE*system*® *i*tself at Site W is concerned, steadily rising air and soil temperatures during this trial (Table 2) would have increased urease enzyme activity, reducing the ability of the nbpt in ONEsystem® to control soil urea hydrolysis (Watson *et al.* 2009). To maintain the advantage of ONE*system*® in late spring and summer on these deep, high organic-matter soils, it is likely therefore that either the concentration of nbpt applied in ONE*system*® needs to be increased, and/or that the nbpt needs to be coated directly onto the prills before application. N recoveries ranged from 54% at the highest N rate to 70% at the lowest (Figure 4(b)), indicating the advantage of a strategy of "following the cows" with low applications of N as ONE*system*®, but these recoveries were still nearly 50% lower than the 90–122% achieved with the various rates of N as ONE*system*® at Site C.

The combination of the relatively efficient (compared to Site C) performance of granular urea at Site W, combined with the relatively poor performance of ONE*system*® for the reasons described, and the variability in growth resulting from the presence of excreta, lead to the absence of a statistically significant advantage to ONE*system*® across the combined rates of N over the full trial period at this site.

However, focusing specifically on the DM obtained at Site W over the full trial duration with a rate of granular urea applied that is near the most typical in farmer practice (e.g., 31.5 kg N/ha at each application, or 126 kg N/ha overall, Figure 2) it is seen that EDM of 1250 kg/ha was obtained (an EDM factor of 9.9). Despite the decline in effectiveness of ONE*system*® during this trial, the same increase in EDM required a total application of only 74 kg N/ha (four applications of 18.5), giving an increased ($P<0.1$) EDM factor of 17.

The high pasture N concentrations achieved with both forms of N at Site W would be expected to result in higher urine-N loadings of the soil during the subsequent grazing. This suggests that individual applications of either form of N should not exceed 30 kg N/ha on these deeper, fertile soils.

Conclusions

These trials showed that ONE*system*®, where urea prills were wetted with water containing nbpt during the application, produced significantly more pasture than from standard application of urea granules containing the same rate of fertiliser N.

The advantage of of ONE*system*® was markedly greater at the Mid-Canterbury (irrigated) site on a stony soil than at the Waikato site on a volcanic ash-derived soil where the advantage to ONE*system*® was limited to early-mid spring (mid-September–mid-October). EDM factors (extra kg DM/kg N applied) at typical rates of N increased from 10 with granular urea at both sites, to 24 and 17 at the two sites with ONE*system*®.

It is concluded that a major advantage of the ONE*system*® is likely to be related to factors associated with the more uniform higher density application of N to plants as urea prills compared to that from the fewer number of urea granules providing the same fertiliser N application rate.

Further research is required on a wider range of soils and environmental conditions in order to provide specific recommendations to farmers on a local basis regarding the advantages of the ONE*system*®.

ACKNOWLEDGEMENTS

Dr M-L Nguyen (Group ONE Consultancy Ltd) is thanked for his comments on the manuscript. This research was funded entirely by Global Sustainable Farming Ltd, 24 Bridge St, Hamilton, 3216, New Zealand. Dr B.F. Quin is a Director of Group ONE Consultancy Ltd, Quin Environmentals (NZ) Ltd and Global Sustainable Farming Ltd. Dr Quin has no pecuniary interest either in Ballance Agri-Nutrients Ltd or in its product SustaiN®.

REFERENCES

Anon, 2008. Nitrogen – Principles of applying nitrogen fertiliser to pasture. DairyNZ, Farm Fact Sheet 7-1. http://www.dairynz.co.nz/page/pageid/2145861419. Updated Nov. 2008.

Argus FMB Nitrogen. 2014. Market Summary – granular urea leads the market higher. Issue 14-31, 31 July 2014, 11 pp.

Ballance Agri-Nutrients. 2015. Key products. http://www.ballance.co.nz/Our-Products/Key-Fertiliser-products. Accessed 16 March 2015.

Bishop, P.; Manning, M. 2011. Urea volatilisation: the risk management and mitigation strategies. In: Adding to the knowledge base for the nutrient manager. Eds Currie, L.D.; Christiensen, C.L. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 24. Fertilizer and Lime Research Cente, Massey University, Palmerston North, New Zealand. 13 pages.

Blennerhassett, J.D.; Quin, B.F.; Zaman, M.; Ramakrishnan, C. 2006. The potential for increasing nitrogen responses using Agrotain treated urea. *Proceedings of the New Zealand Grassland Association 68*: 297-301.

Chien, S.H.; Prochnow, L.I.; Cantarella, H. 2009. Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Advances in Agronomy 102*: 267-322.

Cornforth, I. 1998. Practical soil management. Lincoln University Press, Lincoln University, Canterbury, New Zealand, pp 248.

Dancer, W.S.; Petersen, L.A.; Chesters, G. 1973. Ammonification and nitrification of N as influenced by soil pH and previous N treatments. *Soil Science Society of America Journal 37(1)*: 67-69.

Dewar, K.; Zaman, M.; Rowarth, J.S.; Blennerhassett, J.D; Turnbull, M.H. 2010. The impact of urease inhibitor on the bioavailability of nitrogen in urea and in comparison with other nitrogen sources in ryegrass (*Lolium perenne* L.). *Crop and Pasture Science 61*: 214-221.

Freney, J.R. 2011. Management practices to increase efficiency of fertilizer and animal nitrogen and minimise nitrogen loss to the atmosphere and groundwater. *Food and Fertilizer Technology Centre 186*: 1-22.

Glassey, C.B.; Roach, C.G.; Lee, J.M.; Clark, D.A. 2013. The impact of farming without nitrogen fertiliser for ten years on pasture yield and composition, milk solids production and profitability; a research farmlet comparison. *Proceedings of the New Zealand Grassland Association 75*: 71-77.

Hawkesford, M.J. 2014. Reducing the reliance on nitrogen fertilizer for wheat production. *Journal of Cereal Science 59*: 276-283.

Ledgard, S.F.; Penno, J.W.; Sprosen, M.S. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *Journal of Agricultural Science, Cambridge 132*: 215-225.

Martin, R.J.; Van der Weerden, T.J.; Riddle, M.U.; Butler, R.C. 2008. Comparison of Agrotain-treated and standard urea on an irrigated dairy pasture. *Proceedings of the New Zealand Grassland Association 70*: 91-94.

Roberts, A.H.C.; Thompson, N.A. 1989. Use of nitrogen fertiliser for intensive dairy production. pp. 42-55 In: Nitrogen in New Zealand agriculture and horticulture. Eds White, R.E.; Currie, L.D. Occasional report No. 3. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Stafford, A.; Catto, W.; Morton, J. 2008. Ballance Agri-Nutrients approach to sustainable fertiliser use. pp 197-205 In: Carbon and Nutrient Management in Agriculture. Eds Currie, L.D.; Yates, L.J. Occasional Report No. 21, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Waikato Region Soil Maps. 2015. http://www.waikatoregion.govt.nz/soilsmapsinfo/giswrcmaps.waikatoregion.govt.nz/wrcmaps/Full.aspx?variant=Soil-Risk-for-FDE. Accessed 17 March 2015’.

Watson, C.J.; Laughlin, R.J.; McGeough, K. L. 2009. Modification of nitrogen fertilisers using inhibitors: opportunities and potentials for improving nitrogen use efficiency. *Proceedings of the International Fertiliser Society, London:* ISBN 978-0-85310-295-3.

Zaman, M.; Nguyen, M.L.; Blennerhassett, J.D.; Quin, B.F. 2008. Reducing ammonia, nitrous oxide and nitrate losses from a pasture soil with urease inhibitors and elemental sulphur – amended nitrogenous fertilizers. *Biology and Fertility of Soils 44*: 693-705.