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IODINE SUPPLEMENTATION OF CATTLE

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SUMMARY AND CONCLUSIONS

1. Plasma total iodine (I) and thyroxine are of no practical value to assess I status of cattle. When interpreted carefully, plasma inorganic iodine (PII), is a sensitive index of current dietary I status. PII can confirm suspicions of deficiency or excess of dietary I. Between 1988 and 1999, 32-62% of commercial herds had low or very low I status and the I status of the national herd has fallen since 1995.
2. I deficiency is the most important trace-element deficiency in Irish cattle and sheep. Our ruminants, especially those at pasture, and at critical times of their annual physiological cycle, need routine I supplementation. The most critical times for cows are from 1 month prepartum to 4 months postpartum, except in herds with unexplained abortions, when supplementation throughout pregnancy may be needed. Also, calves, lambs and growing stock may need regular I supplements if unknown factors compromise their performance or immune status.
3 Even in the absence of goitrogens, Irish forages supply <33% of the minimum I needed by cattle and 97% of our forages are deficient in I.
4. Irish mineral mixes supplied circa 32-44 mg I/cow/d in 1989. In the past few years they supply close to 60 mg I/cow/d. Increased use of iodised minerals would greatly improve the I status of the national herd.
5. Oral supplements of 30-60 mg I/cow/d via feed or drinking water maintained normal PII levels. Weekly skin application of 9 ml of 5% tincture of I to the flank-fold pocket was also effective, as was Ionox, a new slow-release bolus. A mean oral supplement (mg I/100 kg LW) of 11.8 is suggested for dairy cows, 4.7 for beef calves, heifers and cows and 6.4 for steers. These are higher inputs than are recommended or used in some countries. However, they are <45% of the inputs defined as safe by EU Feed Legislation, which allows a total intake of 11 mg I/kg feed DM, or 165 mg I/cow/d at an assumed DMI of 15 kg/cow/d.
6. Though Lipiodol injection increased PII for 42-90d, it is not registered on the therapeutic veterinary product list and oral I supplements can maintain normal PII levels for a fraction of its price. Because other methods are effective, faster acting and cheaper, and there is little evidence to support its use as an effective preventative of stillbirth in I deficient herds, Lipiodol is not recommended as an I-supplement for cows.
7. Milk I levels give no cause for concern as regards the risk of human thyrotoxicosis. However, there is a case for monitoring larger numbers of bulk-tank samples and, especially, samples of milk at retail outlets, on grounds of herd health and human health.

INTRODUCTION

Ruminant group mineral status on blood test varies widely on commercial farms. This is because of wide variation in dietary mineral input between ruminant groups, and between seasons in the same group of animals.

Ruminants often have nonclinical mineral imbalances, whose correction, by raising or lowering the supply of the relevant minerals, has no detectable benefit on herd health or productivity. However, it is good policy, nationally and in individual herds, to try to keep dietary and blood mineral status in an optimal range. That range is defined as midway between very low and very high values. As with other minerals, iodine (I) status varies widely in feed and in animals and nonclinical I deficiency is common. However, I deficiency causes severe problems in some herds and flocks.

Clinical and subclinical I deficiency can have serious effects in affected herds. Effects include 10-60% calf mortality (non-specific abortion, stillbirth, weak calves, neonatal calf deaths); calf thyroid enlargement (also in Se deficiency); retained placenta and infertility (especially suboestrus) in >10% of cows and heifers in affected herds; reduced libido in bulls; lower milk yield in cows; illthrift in calves and yearlings; reduced herd immunity to infections

Diagnosis of I deficiency is based the history, local knowledge, clinical signs and postmortem findings. Diagnosis is confirmed by finding thyroid enlargement, hyperplasia and colloid on histopathology, low levels of I in thyroid tissue, or by low I levels in blood- and/or feed samples. Definitive confirmation is based on a dramatic response to I supplementation of the affected animals. [Thyroid enlargement is not definitive for I deficiency- it can also arise in I toxicity and selenium (Se) deficiency].

Before the advent of the plasma inorganic iodine (PII) test (1) no other test was sensitive- or accurate- enough for routine practical use to assess the I status in farm livestock. Dr. David Poole developed the PII test et Grange for routine use in Ireland. PII proved to be most useful for field investigation of problems in Irish herds and flocks. It is very sensitive to current I intake. After an increase or decrease of I intake, PII rises within hours, and falls within days, respectively. PII can confirm a suspicion of clinical or subclinical I deficiency but needs careful interpretation if generous I supplements were given in the 1-7d before blood sampling.

The National Research Council of the United States of America advises that diets free of I antagonists (goitrogens) need at least 0.4-0.8 mg I/kg dry matter (DM) to maintain normal I status in dairy cows. Goitrogens reduce gastrointestinal absorption and/or thyroid-uptake of I. Synthesis of thyroid hormones is disturbed. In goitrogens are present, dietary I may need to be 2-4 mg/kg DM to maintain normal I status (2).

This report summarises:

- the levels of I in (and, thus, the I supply from) Irish cattle supplements and forages
- field- and laboratory- studies that examined PII in cattle
- PII responses to a range of oral I doses for cattle, and a range of options for practical supplementation of cattle with I. The options were I supplements via the feed, summer dairy nut, silage, dairy concentrate, water supply, slow-release bolus, skin application, Lipiodol injection, drenching, and continuous infusion
- Levels of I in samples of bulk-tank milk were noted

The project also covered PII responses in sheep, horses and donkeys, but these data are omitted from this report. The data emphasise that PII falls within days after I supplements are removed and that I deficiency is currently the most important trace-element deficiency in Irish cattle and sheep.

The research suggests the need for routine I supplementation of Irish ruminants, especially those at pasture, and at critical times of their annual physiological cycle. The most critical times for cows are from 1 month prepartum to 4 months postpartum, except in herds with unexplained abortions, when supplementation throughout pregnancy may be needed. Also, calves, lambs and growing stock may need regular I supplements if their performance or immunity is compromised by unknown factors.

1. IODINE IN IRISH MINERAL MIXES AND FORAGES

Poole & Rogers (unpublished) found severely low PII levels (<20 µg/L) in many Irish herds in the late 1980s. From 1989 onwards, severe I deficiency was confirmed in herds from many counties, especially in dry cows. Calved cows, fed compound feeds or mineral mixes high in I, usually had a better I status than dry cows (3). As the inputs of supplementary I from mineral mixtures available on the Irish market, and the I levels in Irish forages on commercial farms were unknown then, it was decided to document them.

1a. I supply from Irish Mineral Mixes in 1989 (4)

Irish-based suppliers replied to a questionnaire on mineral mixes (including mineral blocks and in-feed mixes) for cattle and sheep. Table 1 summarises the data from 27 sources. Daily I supply between formulations intended for specific types of stock varied widely. The companies were encouraged to formulate mineral mixes to provide 30-60 (preferably 60) mg I/cow/d and pro-rata by body weight for other stock.

Table 1. Mean I (mg/head/d) supplied in Irish mineral mixes in 1989. The data were calculated from questionnaire replies from 27 sources.

Cows various	Suckler	Dairy	Cows prepartum	Cows postpartum
34	32	44	38	44
Cows in tetany season	Adults & finishing cattle	Yearlings	Weanlings	Sheep
39	30	23	18	5.2
Ewes	Ewes Prepartum	Ewes Postpartum	Ewes in Tetany season	Lambs
5.6	5.3	8	5.7	3.9

1b. Trace element supplements and perinatal calf deaths (5)

In the early 1990s, Dry-Cow Minerals, specifically low in Ca (0%) and high in Mg (15%) and trace elements, especially Cu, Se and I, were formulated and marketed for the first time in Ireland. Co-Op nutritionists and mineral-compounding companies improved the formulations and labelling of many mineral mixes to bring them more in line with Teagasc advice of that time.

Before the advent of Dry-Cow Minerals, individual farmers had reported high levels of perinatal calf mortality (10-40+%). Calves from primiparous heifers are most at risk, as many farmers fail to provide trace element supplements to their in-calf heifers. In 1991 and 1992, producer groups in many areas reported that provision of good quality Dry-Cow Minerals greatly reduced perinatal calf deaths in their herds. Since then, feedback from Teagasc Advisers and from farmers has supported that observation.

1c. I in Irish Forages (6)

Table 2 summarises the levels of I (mg/kg DM) in Irish forages from 1990-1993 inclusive. Table 3 summarises the breakpoint criteria (mg/kg DM) used to assess the adequacy of I levels in Irish forage as regards suitability for dairy cows, and the % samples in each category in relation to dairy cow requirement. Tables 2 and 3 indicate that the mean I level in Irish forage is grossly deficient for cows; <3% of Irish forages have normal I levels, and most (>97%) have very low or low levels in relation to minimum requirements for cows, even in the absence of goitrogens. Therefore, unless adequate I supplements are given, one would expect most Irish herds to be low in I status on a blood test for PII.

Table 2. Levels of I (mg/kg DM) in Irish forages analysed at Johnstown Castle in 1990-1993 inclusive.

	Herbage					Grass silage					Hay*				
	90	91	92	93	All	90	91	92	93	All	90	91	92	93	All
X	0.224	0.270	0.321	0.378	0.261	0.252	0.275	0.355	0.330	0.269	0.310	-	0.200	0.195	0.225
n	240	460	73	4	777	344	231	36	16	627	1	-	1	2	4
sd	0.168	0.172	0.238	0.134	0.182	0.172	0.168	0.236	0.189	0.177		-	-	-	0.055
se	0.011	0.008	0.028	0.067	0.007	0.009	0.011	0.039	0.047	0.007		-	-	-	0.028
Min					0.05					0.04					0.16
Max					1.00					0.98					0.31

Table 3. Assessment criteria (mg I/kg DM) and the % forage samples in each category in relation to dairy cow requirement for I. Note: Even in the absence of goitrogens, 97-100% of Irish forages have insufficient I for dairy cows.

	Very low	Low*	Normal	High
Assessment breakpoints	< .2	(.2-.4, .4-.8)	>.80	-
% Herbage samples	46.6	(38.1, 12.4)	2.9	0
% Grass silage samples	42.7	(38.6, 16.9)	1.8	0
% Hay samples**	25.0	(75.0, 0.0)	0	0

*** Forage I levels >0.30 mg/kg DM usually indicate sample contamination with soil.**
**** Because of the instability inherent in Irish weather, hay is made with decreasing frequency.**

2. PLASMA INORGANIC IODINE (PII) IN CATTLE

2a. PII in Irish cattle in the 1990s

Through the 1990s, we monitored the I status of herds tested at Grange. Table 4 summarises the data. In spite of mineral supplementation to many herds, low or very low I status occurred in 32-62% of herds. Also, rather than improving, the herd I status has deteriorated since 1995. The reason for the high incidence of low I status is the very transient effect of I-supplements on PII. This means that most herds and flocks have low PII if an adequate I supplement is not provided at the time of blood sampling.

2b. Diurnal PII pattern after I dosing once/d in cattle (7)

Three steers (196, sd 26.9, kg LW) were given 11 mg I/100 kg LW orally. Blood samples were collected at intervals of 4 h thereafter to determine diurnal variation in PII. Mean PII before dosing was 24, sd 13.5, µg/L. The peak value (140, sd 28.4, µg/L) was observed approximately 8 h after dosing.

Table 4. Percentage of Irish herds with mean PII in various categories (VL=very low; LO=low; ML=marginal; NL=normal; HI=high).

Yr	(n) herds	%VL	%LO	%VL+LO	%ML	%NL	%HI
91	642	33.00	24.60	57.60	15.70	23.70	3.00
92	1068	38.10	24.30	62.40	22.10	14.30	1.20
93	1158	32.90	24.50	57.40	22.80	17.40	2.30
94	1190	18.40	19.70	38.10	25.60	31.70	4.60
95	900	14.60	17.60	32.10	23.70	39.00	5.20
96	755	18.70	17.70	36.40	22.40	35.50	5.70
97	455	28.10	15.20	43.30	25.70	28.10	2.90
*98	**	35.29	15.05	50.34	18.14	22.75	8.77

*** The data for 1998 are estimates only. **The 1998 estimates are based on PII in 7861 individual blood samples, excluding samples taken in connection with the abattoir survey of trace element status in cattle. Those data will be reported elsewhere; they show that >80% of cattle (culled dairy cows, culled suckler cows and finished cattle) slaughtered in autumn have low I status.**

2c. Relationships between PII, plasma total I (TOTI) and thyroxine in cattle (9)

In the trial described in 3d, below, the relationships between the levels of PII (µg/L), plasma total I (TOTI in µg/L) and thyroxine (T4, in nmol/L) were examined in Friesian steers (n=6/treatment). A subset of bloods (n=72) was chosen to reflect a wide range of PII values. The relationships between PII, TOTI and T4 were: PII = 0.24*TOTI + 12.7 (r^2=0.51, p <0.01); PII = -0.85*T4 + 101.2 (r^2=0.05, p > 0.05); TOTI = -2.08*T4 + 261.4 (r^2=0.04, p > 0.05). As PII closely reflects current dietary I intake and blood I status (see most of the trials in this report), the poor relationships between TOTI, T4 and PII confirm that TOTI and T4 are of no practical value in assessing the I status of cattle.

3. METHODS OF IODINE SUPPLEMENTATION

Systems of summer- and winter- management of cattle and sheep vary widely on commercial Irish farms. Thus, Irish farmers need a range of options from which to select the one(s) most suited to their system. The more common options for I supplementation are via the feed, water supply, slow-release bolus, skin application, Lipiodol injection, or by periodic drenching. All of these options were examined under experimental conditions.

3a. I supplementation of cattle via feed

Mineral supplementation via the feed is the cheapest and most effective way to ensure optimal mineral status in livestock. If animals are fed concentrate rations, whether at a high level indoors in winter, or at a low level as a supplementary summer feed at pasture, the concentrate can be used to carry any mineral, or other, supplements that may be needed.

I supplementation of cows via a mineralised summer dairy nut
Three field studies assessed Co-Op Summer Feeds as vehicles for trace element supplements in 1992-1994.

a. NCF trial 1992 (10)
In 1992, North Connaught Farmers Co-Op (NCF) prepared a Summer Feed containing 360 mg Cu, 3.6 mg Se and 45 mg I in the daily allowance. After circa 4 months, levels of Cu, glutathione peroxidase (GPx) and PII were determined in blood samples from 10

cows/herd in 16 herds fed the NCF summer feed. Table 5 summarises the results. Compared to other herds in Connaught at the time, NCF herds had a greatly improved Se and I status of dairy cows, but the blood data suggested that better results could be attained if the supply of trace elements were increased.

Table 5. For details of the trial, see NCF trial 1992, above. Mean Cu (µmol/L), GPx (iu/g Hb) and PII (µg/L) in the NCF herds versus other Connaught herds.

	Cu (n)	GPx (n)	PII (n)
NCF Herds	#11.37 (16)	64.6 (16)	100.5 (16)
Other Herds	#11.62 (29)	51.1 (31)	58.4 (21)
Sig.	ns	*	***

Mean blood Cu was normal in both groups

b. NCF trial 1993 (11)

NCF increased the Cu, Se and I in its Summer Feed, so that the daily allowance (2 kg) supplied 450 mg Cu, 7 mg Se and 60 mg I/cow/d. The status of Cu, Se and I in the blood of 17 herds on that feed for about 4 months was compared with the status for the rest of the country in the same month (August). Table 6 summarises the results. The 1993 programme was highly successful in maintaining normal blood levels. It gave the best set of blood values from commercial herds ever recorded in this laboratory. Of the herds tested, 100% had normal Cu and Se status. Apart from 15% marginal herds, I status was also normal.

Table 6. For details of the trial, see NCF trial 1993, above. Mean and se for Cu (µmol/L), GPx (iu/g Hb) and PII (µg/L) in the NCF herds versus other Connaught herds.

		Cu µmol/L	GPx iu/g Hb	PII µg/L
NCF herds	n	17	17	17
Other herds	n	55	53	63
NCF herds	X	11.85	89.2	125.3
Other herds	X	11.37	55.4	43.2
NCF herds	se	0.148	2.025	11.642
Other herds	se	0.247	2.558	4.460
Difference	Sig.	*	***	***

c. Waterford trial 1994 (12)

In 1994, Waterford Co-Op sold a Summer Nut (Gain) with 398 mg Cu, 4.8 mg Se and 43 mg I in the daily allowance. Blood samples were taken from 10 cows/herd fed on the feed for at least 4 months. Samples were taken also from 10 unsupplemented follower cattle/herd for comparison. Table 7 summarises the results. The summer feed markedly improved the Cu, Se and I status of supplemented cows, as compared with unsupplemented young stock in the same herds. In the catchment area of the trial, marginal to very low PII (I) status occurred 83.3% of 60 herds, as compared with 100% of 12 other unsupplemented herds (young stock) in the trial and 81.8% of the 11 supplemented cow herds. Note that the I-supplement increased PII significantly but the mean PII was marginal, as the input of I (43 mg I/cow/d) was below optimum (60 mg I/cow/d).

Table 7. For details of the trial, see Waterford trial 1994, above. Mean and se for Cu (µmol/L), GPx (iu/g Hb) and PII (µg/L) in the Waterford Gain herds versus control herds in the catchment. Note that the I-supplement increased PII significantly but the mean PII was marginal, as the input of I (43 mg I/cow/d) was below optimum (60 mg I/cow/d).

		Cu µmol/L	GPx iu/g Hb	PII µg/L
Treated Herds	X	12.52	96.77	79.28
	se	0.20	2.59	5.17
Control Herds	X	11.27	43.58	22.08
	se	0.28	1.79	2.67
	Sig.	***	***	***

Conclusions on Summer Feeds:

From these three field studies, feeding of Summer Feeds at fixed rates to provide 40-45 mg I/cow/d greatly improved PII status in dairy cows and summer feeds supplying circa 60 mg I/cow/d maintained mean PII levels in the normal range.

I supplementation of beef cows via silage (13)

Earlier work indicated that dairy cows need about 50-60 mg I/cow/d to keep herd mean PII >105 µg/L. In 1994, supplementation of beef cows with 36 mg I/d seemed to keep mean PII >105 µg/L. This suggested that beef cows may have a lower requirement for I than dairy cows. A trial in 1994-95 monitored PII levels in 4 groups of 9 beef cows individually fed a mineral mixture sprinkled over easy-feed silage, to supply 0, 16, 32 or 65 mg I/cow/d before calving. The cows were bled twice pretrial. The mean PII value for each cow was taken as the pretrial (starting) value. On 2/12/94, the cows were allocated to their treatments. On d 23, all supplements were removed. The cows were bled (while off minerals) on d 41 and 48. On d 48, the treatments were changed to 32, 16, 16 and 16 mg I/cow/d respectively. The cows were bled again on d 62, 76, 90 and 104, while still on those treatments. On d 104, the supplement to Gp 0 was reduced to 16 mg I/cow/d, the same as for Gps 1, 2 and 4. On d 124, the cows were bled again and all minerals were withdrawn immediately afterwards. The cows went to grass (between d 131 and 144). A final blood sample was taken on d 165 from unsupplemented cows at pasture. PII was determined on all plasma samples. Table 8 summarises the results. Mean PII values for sets when I supplement was 0, 16, 32 and 65 mg were 11, 74, 147 and 271 µg/L respectively. The data confirm that beef cows in late pregnancy may need only 30-35 mg I/cow/d to maintain PII >105 µg/L, and that inputs of 65 mg I/cow/d may occasionally increase PII above the upper reference range for normal bovine PII (285 µg/L).

Table 8. For details of the trial, see <u>I supplementation of beef cows via silage</u>, above. Treatment means for PII (µg/L) in beef suckler cows pretrial and up to 165 d after the start of the trial.

TR	d0	d13	d34	d41	d48	d62	d76	d90	d104	d124	d165
0	8.7	11.1	8.1	8.6	8.0	120.0	166.2	137.4	138.1	69.8	12.1
1	8.3	102.9	56.4	11.6	12.2	61.8	79.7	66.4	83.0	50.2	11.7
2	9.6	203.1	114.6	14.3	13.9	82.7	92.1	73.9	105.7	57.0	14.0
4	7.0	375.0	166.8	19.1	11.4	64.1	77.0	65.0	78.7	61.3	13.2

Underlined means were for dates when no supplement was given. Italicised means were for dates when 32 mg I was being fed. Bold means were for dates when 65 mg I was being fed. All other means were for dates when 16 mg I was being fed.

I supplementation of dairy cows via silage (14)

A split-herd, randomised mineral-vitamin supplementation experiment was carried out over two years in a large, trace element deficient dairy herd. Ten weeks before the mean calving date, 147 Holstein-Friesian cows were fed grass silage on to which 50 g/cow of a mineral-vitamin supplement (3000 mg copper, 500 mg iodine, 45 mg selenium and 80 mg cobalt per kg of supplement) was sprinkled twice daily until calving. Mean PII levels before trial were 19 µg/L (very low). Table 9 summarises the PII levels (with SD) during the trial. The Dry Cow Mineral supplement significantly increased the levels of trace elements, including PII, in the blood of the cows and newborn calves in the supplemented group. It also significantly increased the levels of trace elements in the blood and tissues of dead perinatal calves from 10 supplemented dams compared with those from eight unsupplemented dams.

Table 9. For details of the trial, see <u>I supplementation of dairy cows via silage</u>, above. Mean PII levels (µg/L, with SD) in dairy cows at 2 to 15 weeks after treated cows had access to silage treated with a Dry-Cow Mineral. Mean PII levels (all cows) before the trial were 18.8 µg/L (very low). Levels remained very low in the control cows but were normal at all samplings in the treated cows.

Week after start of trial	2	5	10	15
Treated cows	145.0 (52.0)	106.7 (37.0)	121.5 (42.2)	133.9 (49.4)
Control cows	13.4 (5.3)	8.7 (4.7)	14.4 (9.7)	18.6 (25.2)
Significance of difference	*	*	*	*

I supplementation of cattle via a molasses-based silage additive (15)

Temol (Premier Molasses, Foynes) is a molasses-based silage additive containing added trace elements. The effectiveness of I supplementation of cattle by the addition of Temol to herbage at ensiling was tested. Temol-treated and control- silage was fed to heifers, with and without additional inorganic mineral mix in concentrates. Temol significantly increased PII in heifers. However, the method needs more research before it can be recommended as national policy.

Oral I supplementation of beef steers (16)

Housed continental steers (n=48, mean circa 500 kg LW) were offered ad-libitum silage + 1.5 kg rolled barley twice/d. No mineral mixture was fed. Mean LW and PII levels in heparinised blood were established for each animal twice pretrial. The overall mean pretrial PII was 20 µg/L (very low). The steers were assigned at random to 8 groups (n=6/group): Gp 1=Untreated controls; Gps 2, 3 and 4=20, 40 and 60 mg I/600 kg LW/d for 30 d; Gps 5, 6 and 7=20, 40 and 60 mg I/600 kg LW/d for 60 d; Gp 8=4 ml Lipiodol, 40% I, injected once. (The Lipiodol results are given separately, see 3e.b, below). The oral I supplement used was a solution of potassium iodide (KI), which contained 2.5 mg I/ml, given at 20, 40 or 60 mg I/600 kg LW/d, representing doses of 33 to 100% of the top dose advised for dairy cows. Half of the dose was sprayed on the concentrates twice/d. After d0, all steers were bled weekly for PII. The steers were bled frequently up to 19-21d after withdrawal of I (d30 in Tr 2-4; d60 in Tr 5-7). Mean values for PII and mean changes from baseline (Subsequent minus Pretrial values) were calculated for each group. The rate of fall of PII after withdrawal of KI was monitored. Table 10 summarises the results. Control PII values remained very low throughout. As in earlier studies, PII increased as oral I supply increased. In the 30-d trial, relative to PII changes in controls, daily oral supplements of 20, 40 and 60 mg I (as KI)/600 kg LW increased PII (p<.001) by a mean of 94, 180 and 261 µg/L across all samplings while on supplement. On withdrawal of the supplement after 30d, PII fell sharply; by d6 post-withdrawal, the previous level of supplementation had no significant effect on changes from pre-supplementation values. In the 60-dtrial, relative to PII changes in control steers, the supplements increased PII (p<.001) by a mean of 94, 153 and 286 µg/L across all samples. On withdrawal of I supplement after 60d, PII also fell rapidly but took some days longer to reach control levels than in the 30-dtrial; by d12-15 post-withdrawal, the previous level of I supply had no significant effect on changes from pre-supplementation values. In this trial, daily dietary supplements of 20-40 mg I/600 kg LW were optimal for Continental X cattle. These levels are slightly lower than those (30-60 mg I/cow/d) advised for Friesian cows.

Oral I supplementation of beef heifers (17)

Housed continental-cross heifers (n=50, mean circa 518 kg LW) were offered ad-libitum silage + 1.5 kg rolled barley twice/d. A low-I mineral mixture was fed. Mean LW and PII levels in heparinised blood were established for each animal pretrial. The overall mean pretrial PII was 23 µg/L (very low). The animals were assigned to 5 treatment groups (n=10/group): Gp 1=Untreated controls; Gps 2, 3, 4 and 5=oral KI solution sprayed on the on the silage once/d to provide 10, 20, 40 and 60 mg I/600 kg LW/d for 21 d. All animals were bled 4 times for PII while on treatment. Mean values for PII and mean changes from baseline (Subsequent minus Pretrial values) were calculated for each group. Table 11 summarises the results. Control PII values remained very low (<25 µg/L) to low (<50 µg/L) throughout. As in earlier studies, PII increased as oral I supply increased. Daily oral supplements of 0, 10, 20, 40 and 60 mg I)/600 kg LW increased PII (p<.001) by a mean of 14, 74, 131, 233 and 318 µg/L respectively (sem 25.8). The data confirm earlier work that suggested that cattle on home-grown forage + unsupplemented

meals need a substantial I supplement to maintain PII levels in the normal range. Mean PII increments of 131-233 µg/L from daily oral doses of 20-40 mg I/600 kg LW were enough to maintain PII in the normal range in continental-cross heifers. The data also agree with previous data which suggested that beef-cross cattle may need less I supplement than Friesians.

Table 10. For details of the trial, see <u>oral I supplementation of beef steers</u>, above. Mean blood PII (µg/L) pretrial, during trial and post-withdrawal (- prefix) of an oral I supplement (Gps 1, 2, 3 and 4) and changes from baseline values.

Gp	Pre	8	15	22	29	-3	-6	-9	-12	-15	-18	-21
1	20	19	20	13	10	10	8	9	7	6	6	3
2	20	102	117	125	81	39	14	22	11	8	11	7
3	21	228	198	208	138	60	18	22	13	7	14	6
4	19	295	240	343	212	86	23	20	12	12	13	6
sem	3.29	21.8	24.6	28.5	22.6	8.45	2.82	1.68	0.85	1.29	0.98	1.04
Pr<F	ns	***	***	***	***	***	*	***	**	*	***	ns
Changes from baseline values were:												
1	-	-2	0	-7	-10	-10	-12	-11	-13	-14	-14	-17
2	-	82	97	105	61	19	-6	2	-10	-13	-9	-13
3	-	207	176	187	117	39	-4	1	-9	-14	-8	-15
4	-	276	220	324	193	67	-4	1	-8	-7	-6	-13
sem	-	22.2	24.2	28.7	23.2	9.1	3.94	3.66	3.26	3.42	3.53	3.37
Pr<F	-	***	***	***	***	***	Ns	ns	ns	ns	ns	ns

Mean blood PII (µg/L) pretrial, during trial and post-withdrawal(- prefix) of supplement (Gps 1, 5, 6 and 7 only) and changes from baseline values were:

Gp	Pre	8	15	22	29	36	43	50	57	-3	-6	-9	-12	-15	-19
1	20	19	20	13	10	10	7	5	8	16	11	12	12	12	9
5	19	112	120	103	85	130	89	98	103	99	37	29	19	14	9
6	19	213	136	199	127	217	127	142	147	151	48	36	19	15	10
7	18	315	270	385	218	373	210	273	326	257	92	42	25	18	11
sem	3.18	16.4	19.7	26.3	15.7	20.0	8.6	15.5	15.4	16.0	8.2	3.1	1.4	1.1	0.7
Pr<F	ns	***	***	***	***	***	***	***	***	***	***	***	***	**	ns
Changes from baseline values															
1	-	-1	0	-7	-10	-10	-13	-15	-12	-5	-10	-9	-9	-8	-11
5	-	93	101	84	66	111	70	79	84	80	18	10	8	-5	-10
6	-	194	117	180	108	198	108	123	128	132	29	17	0	-4	-9
7	-	297	252	367	200	354	192	255	308	239	73	24	7	0	-8
sem	-	16.6	19.3	25.2	15.8	19.4	7.8	16.8	15.7	16.4	8.7	4.9	3.3	2.9	3.3
Pr<F	-	***	***	***	***	***	***	***	***	**	***	***	*	ns	ns

Table 11. For details of the trial, see oral I supplementation of beef heifers, above. Mean blood PII (µg/L) pretrial, during oral I supplementation, change at from baseline at S1 to S4 (I1 to I4), overall mean on treatment, and mean effect of treatment.

Tr	Pre	S1	S2	S3	S4	I1	I2	I3	I4	On Trial#	Gross Effect~	Net Effect!
1	23.3	38.5	48.1	30.6	33.6	15.2	24.8	7.3	10.3	37.7	14.4	0.0
2	21.5	90.9	114.6	88.5	89.1	69.4	93.1	67.0	67.6	95.8	74.3	59.9
3	24.0	142.3	177.4	152.9	148.6	118.3	153.4	128.9	124.6	155.3	131.3	116.9
4	23.0	235.3	246.4	271.1	272.1	212.3	223.4	248.1	249.1	256.2	233.2	211.8
5	21.5	341.7	289.2	376.8	351.9	320.2	267.7	355.3	330.4	339.9	318.4	304.0
sed	1.5	24.4	11.8	25.1	19.1	24.3	11.4	24.8	18.7	16.7	16.3	16.3
Sig	ns	***	***	***	***	***	***	***	***	***	***	***

Mean PII on trial was based on the mean value of 4 blood-samplings (S1 to S4) during the 21-d trial period.

~ The mean effect was based on [(the mean "On Trial" value) minus (the Pre value)]

! The mean net effect was based on [(the mean "On Trial" value) minus (the Pre value) minus the change in the untreated controls (Gp 1)]

Oral I supplementation of suckler cows (18)

Suckler cows in late pregnancy were very low in PII on 20/1/94 (mean 23.3 µg/L). From stat, a mineral mix (nominally 300 mg I/kg) was fed individually to supply a nominal 18 mg I in 60 g/cow/d. By d 3, mean PII had increased by 31 µg/L. Within breed (HerX and ChX), the cows were sorted by PII on d -4 and assigned at random to 4 groups of 6 cows each: control (no I supplement) from d 7 to d 16; 18 mg I/cow /d; 36 mg I/cow/d; 72 mg I/cow/d, fed individually in a mineral mix sprinkled on the silage once/d. The cows were bled on d 3, d 10 and d 17, after which the 18 mg I dose was given to all groups. While on that dose, the cows were bled again on d 18, 24 and 45. Table 12 summarises the results. In suckler cows, it seemed that there is a carry-over effect from previous I treatment and that 36-72 mg I/d is enough to maintain PII >100 µg/L.

Table 12. For details of the trial, see Oral supplementation of suckler cows with I, above. Treatment mean PII levels (µg/L) in suckler cows on or off an oral supplement of 0, 18, 36 or 72 mg I/cow/d.

Tr Gp	20/1 (Pre)	d 3	d 10	d 17	d 18	d 24	d 45
1	#21.2	*54.0	#16.3	#13.3	*34.7	*58.0	*63.7
2	#26.0	*58.2	*77.0	*67.5	*80.8	*75.8	*78.8
3	#23.3	*55.7	**126.2	**103.5	*112.7	*78.8	*90.0
4	#22.8	*50.0	***172.3	***187.5	*153.0	*85.8	*97.2

The I doses were #0, *18, **36, or ***72 mg/cow/d

I supply from foreign Dairy Cow Concentrates (19)

To ascertain the daily inputs of minerals and vitamins from foreign dairy concentrates, a questionnaire was sent in 1996 to dairy-feed manufacturers abroad. Minimum, maximum and usual (typical) feeding rates of branded dairy feeds, and the total levels of minerals and vitamins in those feeds were recorded. Three categories of dairy rations were examined: A=Concentrate fed at very high rates (usually >12 kg/cow/d); B=Concentrate fed at medium rates (usually 4-12 kg/cow/d); C=Concentrate to be fed at low rates (usually 1-4 kg/cow/d). Concentrates in category C were usually, but not always, used as summer-feeds at pasture. Thirteen companies in 10 countries (Australia, Belgium, Canada, Denmark, Korea, Republic of China (Taiwan), South Africa, Switzerland, UK and USA) gave useful replies. Table 13 summarises the results. Mean I inputs used in foreign dairy feeds are much lower than those used in Ireland, and allowed as safe under EU Feed Legislation.

Table 13. Foreign manufacturers' mean recommended feeding rates, and the I specification of the dairy feeds in categories (Cat) A, B and C.

Cat	Minimum (kg/cow/d)	Maximum (kg/cow/d)	Usual (kg/cow/d)	I level (mg/kg)	I supply (mg/cow/d)
A	12.5	16.9	15.1	0.7	11.0*
B	3.6	8.6	5.9	2.2	12.1*
C	1.9	4.4	2.9	5.3	10.2*

*Mean daily I supply masks variation between countries, between companies and, even inputs between different rations formulated by the same company, and between feeding rates advised by the company.

3b. Water delivery systems and I supplementation of cattle via the drinking water

3b.1 Accuracy of Dosatron pumps for water medication (20)

To monitor of the effectiveness of pumps to medicate water supplies, delivery of a soluble mineral salt from four Dosatron pumps was tested at dose/water ratio settings of 1.0, 0.78 and 0.39%. At water flow rates of 400-500 l/h, the pumps delivered 2-11% more product than expected at the settings used. At a dose/water ratio setting of 1% (the setting most often used), mean output exceeded specification by 6% and the mean range between pumps was 5-9% above specification. Slow flow rates (80 l/h) tended to increase product output by a further 3-4% units. Slight overdosing is preferable to underdosing.

3b.2. Aquadyne in water: Rate of I release after immersion of tablets (21)

Aquadyne tablets (Mayo Healthcare, Westport) have an insoluble matrix to contain soluble I salts, nominally 420 mg I/tablet respectively. They are used via the trough water supply as I supplements for cattle. They are inserted (1 tablet/7 cows/d) at one end of a simple dispenser immersed in trough-water. As the dispenser becomes full, spent wet tablets are removed from the opposite end. This study monitored:

a. the I content of fresh Aquadyne tablets
b. the DM loss of tablets removed from troughs after up to 15 d immersion in a field-situation
c. the DM loss of tablets in a controlled situation and
d. the rate of I release from Aquadyne from the tablets over a 7-d period.

(a) Fresh tablets contained 98% of the nominal I value. (b) When converted to KI equivalent of the fresh weight of KI, tablet DM loss over a period of immersion of up to 15 d in a field-situation was 97% of the assayed KI value. (c) Tablet DM loss in a controlled situation was studied by an adaptation of the nylon-bag technique, as used in rumen-digestibility studies. Air-dry weights of 10 bags were recorded after 1h at 80°C. A tablet was placed in each of the bags. The air-dry weight (after 2h at 80°C) of the bag + tablet was recorded pre-immersion and after 24, 48, 72, 96, 120 and 144 h after immersion in the barrel system, as used in (d), below. Table 14 summarises the results. Mean tablet DM loss after immersion in water for 24h was 78% of the maximal DM loss, i.e. most of the loss was in d1 and >99% was lost by d5. (d) Tablet I release rate over 7d was assessed by immersion in a system that mimicked ball-cock controlled troughs in field use. I was assayed in fresh tablets and in tablets removed after periods of immersion of 1, 3, 5, 9 and 24h and at 2, 3, 5 and 7 d (48, 72, 120 and 168h). A total of 60 I tablets (6 fresh, 54 removed from the dispensers at the specified times) were sent for I assay. Each tablet was ground individually and analysed for its total content of I. Table 15 summarises the results. In basic agreement with DM loss, as found in (3b.2) above, 76% of the I loss occurred within 24 h after immersion in water and >99% was lost by d5.

Table 14. For details of the trial, see Aquadyne in water: Rate of I release after immersion of tablets, above. Tablet DM loss (g) and % of active ingredient lost after immersion of Aquadyne tablets for 0-144h.

	0	24h	48h	72h	96h	120h	144h
X	0	0.408	0.490	0.512	0.512	0.519	0.52
Sd	0	0.039	0.053	0.054	0.054	0.050	0.052
Loss/total loss %	0	78.5	94.2	98.5	98.5	99.8	100

Table 15. For details of the trial, see Aquadyne in water: Rate of I release after immersion of tablets, above. I loss (mg) and % of total I lost after immersion of Aquadyne tablets for 0-168h.

	0h	1h	3h	5h	9h	24h	48h	72h	120h	168h
Mg active element	410.82	325.48	261.7	242.25	204.27	99.1	26.1	6.15	0.28	0.05
sd	0.25	23.65	33.14	19.36	24.82	10.55	6.59	3.43	0.16	0.05
% loss of total I	0	20.77	36.30	41.03	50.28	75.88	93.65	98.5	99.93	99.99

To ensure regular and even intake of dissolved I by cattle, daily Aquadyne medication of the water is preferable to weekly medication.

3b.3. I supplementation via the water supply for steers

Grange adopts 105-285 µg PII/L as the normal group mean but some authors accept a lower "normal" threshold (>70 µg/L). Early work suggested that Friesian (Fr) cows need 8-10 mg I/100 kg LW/d, orally in, or on, the feed, whereas continental-cross cows and cattle need only 4-6 mg I/100 kg LW/d, to maintain PII in the mid-normal range (125-200 µg/L). The following two experiments assessed the effect of I via the water supply on PII of steers.

Exp. 1 (1990): Flowtrace in the water supply for steers (22)

Grazing Friesian (Fr) steers (5 groups, 12/group, mean 295 kg), were offered for 165d: A KI in a carrier feed to supply 10.4 mg I/100 kg LW/d; B, C, D KI via drinking water at 50, 100 and 150% of dose A, or E no I supplement. Gps B-E also got unmedicated carrier. No other minerals were supplied. Mean PII levels in heparinised blood were very low pretrial (7-8 µg/L). Table 16 summarises the results. PII stayed very low throughout in the control cattle (Gp E). Relative to control changes, I supplement significantly raised PII levels in a dose-related manner in Gps A-D by 116, 48, 114 and 149 µg/L. At equivalent I-inputs (Gps A and C), medicated feed or water were equally effective and a dose rate of 10.4 mg I/100 kg LW/d was enough to maintain normal PII levels in Friesian steers (22).

Table 16. For details of the trial, see Exp. 1 (1990): Flowtrace in the water supply for steers, above. Mean PII levels in steers on oral I supplements (A) of 10.4 mg I/100 kg LW/d in a carrier feed, and (B, C, D, E) 5.2, 10.4, 15.6 and 0 mg I/100 kg LW/d via drinking water.

Tr	Pre	S1	S2	S3	On trial	Net Change (On trial - Pre)	Net Effect
A	7.9	158.1	156.3	55.3	123.2	115.3	115.8
B	7.2	39.9	65.8	59.0	54.9	47.7	48.2
C	7.4	96.5	176.3	88.5	120.4	113.0	113.5
D	6.7	127.2	213.0	125.3	155.2	148.5	149.0
E	6.9	5.6	5.3	8.3	6.4	-0.5	0.0
Sig.	ns	***	***	***	***	***	***

Exp. 2 (1996): Aquadyne in the water supply for steers (23)

In earlier work, Friesian cows and young stock needed an oral supplement of 50-60 mg I/600 kg LW/d to maintain PII in the low-normal to mid-normal range (125-200 µg/L). Continental-cross cows and young stock needed less I (25-35 mg I/600 kg LW/d) to maintain similar PII levels. Those findings spanned a 5-year period, at different times and under different circumstances. Thus, the apparent difference in requirement for I between Friesians and Continental crosses could be due to factors other than breed. The following trial assessed the potential of Aquadyne medication of trough-water (Mayo Healthcare, Westport, 420 mg I/tablet) to control I deficiency in yearling steers at pasture and to examine if there was a breed-effect on the PII response to medicated water. Two groups of 25 grazing beef cattle, mean 16 months old and 404 kg at the start of the trial, were studied. Each group contained 13-12 Charolais X Friesian (ChX) and 12-13 Friesian (Fr) cattle. Cattle were sorted by LW within type within grazing area. From the sorted list, 4 ChX and 4 Fr cattle/group (total=8 ChX and 8 Fr cattle, mean 404 kg) were selected at random. The 16 selected cattle were colour-tagged and blood sampled at intervals to monitor the PII response to I medication. Each animal was used as its own control. As other trials had indicated that the I requirement of beef cattle may be less that that of dairy cattle, Aquadyne was given at half the recommended dose via the trough-water supply; the trough was medicated with 0.119 Aquadyne tablets/1000 kg LW/d for 14d, starting at 0900h on July 15 (d1) and continuing to 0900h on July 28 (d14) inclusive. This supplied 5 mg I/100 kg LW/d for 14d. Any tablets remaining in the trough were removed at 0900h on July 29 (d15). Blood was taken for PII assay from the 16 cattle twice in the days just before the trial began, and at 0900h on d2, 5, 8, 11, 15, while with access to medicated water, and on d29 and 36 (14 and 21d after the dispenser was removed). Differences in mean PII for the period on treatment versus the periods off treatment (Pre + Post) were calculated and were used to assess the effect of treatment. Table 17 summarises the results. The data confirmed the sensitivity of PII to current I inputs. Overall mean PII levels pretrial (9.5 µg/L) were very low. The supplement significantly increased PII levels (by a mean of 63 µg/L) but was not enough to normalise PII. The increase due to I medication in Fr cattle (mean 60 µg/L) was not significantly different from that in ChX cattle (mean 67 µg/L). Overall mean post-trial values (16.1 µg/L), though 6.6 µg/L above those pretrial, had fallen to very low levels again at 14 and 21d after withdrawal of I supplement. As in other trials, the beneficial effects of supplementation on PII levels had almost disappeared within 2 weeks. The data suggest that steers need >5 mg I/100 kg LW (close to 10 mg I/100 kg LW) and that breed had no significant effect on PII response (23).

Table 17. For details of the trial, see Exp. 2 (1990): Flowtrace in the water supply for steers, above. Mean PII levels (µg/L) in continental-cross (ChX) steers (n=8) and Friesian (Fr) steers (n=8) before, during (d1-d14) and after (d-14 and d-21) I supplementation with Aquadyne via the water supply.

Breed		Pre	d1	d4	d7	d10	d14	d-14	d-21	Post	Off	On	Effect
ChX	X	9.7	21	88.5	105.5	119.9	65.6	17.5	17.0	17.3	13.5	80.1	66.6
Fr	X	9.3	22.5	90.6	91.0	104.6	49.8	14.9	15.0	14.9	12.1	71.7	59.6
	sem	0.8	3.16	19.5	32.8	25.8	15.0	1.8	1.04	0.83	0.53	13.5	13.9
	Sig	ns	ns	ns	ns	ns	ns	ns	ns	**	**	ns	ns

As assessed by PII responses in those two experiments (22, 23), medicated drinking water was an effective I supplement for steers. To keep PII >105 µg/L, both Fr and ChX steers need an I supplement in water of >5 mg I/100 kg LW/d (Exp. 2) to 10.4-15.6 mg I/100 kg LW/d (Exp. 1).

3b.4. Aquadyne in the water supply for suckler cows and calves (24)

The potential of I medication of trough water was assessed as to its ability to control I deficiency (maintain PII in the range 100-300 µg/L) in beef cows and their suckling calves at pasture. Water was medicated with Aquadyne tablets, nominally of 420 mg I each. As other trials had indicated that the I requirement of beef cattle may be less than that of dairy cattle, Aquadyne was given at half the recommended dose via the trough water supply. The water trough available to grazing suckler cows and their calves was medicated with 0.119 tablets/1000 kg LW/d, starting at 0900h on 29/7/96 (d1) and continuing to 0900h on 11/8/96 (d14) inclusive. This supplied 30 mg I/600 kg LW/d for 14d. Any tablets remaining in the trough were removed at 0900h on 12/8/96 (d15). No tablets were removed from the dispenser until it was removed from the trough on d15. Grazing Limousin x Friesian beef suckler cows (n=11) and their 4-month-old calves (n=11), sired by a Charolais or Simmental bull, were bled twice for PII assay before, and at 0900h on d2, 5, 8, 11, 15 (while with access to medicated water), and on d29 and 36 (14 and 21d after the Aquadyne dispenser was removed). Each animal acted as its own control. Differences in mean PII for the period on treatment versus the periods off treatment (Pre + Post) were calculated and were used to assess the effect of treatment. Table 18 summarises the results. The supplement increased PII levels by a mean of 42 µg/L (p<.001) but was not enough to normalise PII. Mean PII increases in the cows (43 µg/L) and calves (41 µg/L) were not significantly different from each other, suggesting that the calves must have drunk similar amounts of medicated water/kg LW as the cows. The data also confirm the sensitivity of PII to current I inputs. Overall mean PII levels pretrial (cows 5.1, calves 7.0 µg/L) were very low. Overall mean post-trial values (cows 11.1, calves 14.3 µg/L), though 6 to 7 µg/L above those pretrial, had fallen to very low levels again at 14 and 21d after withdrawal of I supplement. As in other trials, the beneficial effects of supplementation on PII levels had almost disappeared within 2 weeks. The data suggest the need for a dose closer to 60 mg I/600 kg LW if one is to maintain PII in the range accepted as normal.

Table 18. For details of the trial, see <u>Aquadyne in the water supply for suckler cows and calves</u>, above. Mean PII levels (µg/L) in suckler cows (n=11) and calves (n=11) before, during and after I supplementation with Aquadyne via the water supply.

	Pre	d1	d4	d7	d10	d14	d-14	d-21	Post	Off	On	Effect
Cows X	5.1	13.1	46.1	69.5	50.1	74.3	15.0	7.1	11.1	8.1	50.6	42.5
se	0.41	0.65	3.03	4.94	8.01	5.15	0.90	0.77	0.67	0.46	3.68	3.41
Calves X	7.0	14.5	41.3	69.1	51.4	79.2	18.9	9.6	14.3	10.6	51.1	40.5
se	0.6	1.3	7.3	9.8	12.6	12.6	1.6	0.9	1.2	0.8	8.2	8.0
Sem	0.74	1.42	7.94	11.00	15.00	13.60	1.81	1.17	1.36	0.95	9.02	8.69
Sig	**	ns	ns	ns	ns	ns	*	*	*	**	ns	ns

3b.5. Aquadyne in the water supply for dairy cows (25)

In a randomised controlled trial, Moorepark Holstein cows (568 kg) got 3 treatments (n=10 cows/treatment) over 28d, F (full dose, 1 Aquadyne tablet (420 mg I)/7 cows/d), H (half dose, 1 tablet/14 cows/d), C (unmedicated water). PII was measured twice pre-medication, 4 times (days 7, 14, 21, 28) on medication and twice post-withdrawal of medication (d7 and 14 after removal of I tablets. All 3 groups had very low mean PII (15-20 µg/L) pre-medication. While on medication, mean PII in Gp C stayed very low (16-22 µg/L). PII rose in Gps H and F, to range from 41-72 and 75-103 µg/L, respectively, with large variation within each group. Post-withdrawal of medication, mean PII had returned to pre-medication levels within 7d. Table 19 summarises the results. Mean PII changes (On-Phase - Off-Phase) in dairy cow Gp C versus Gps H and F (water medication with I tablets to supply 30 or 60 mg I/cow/d) were 0.4, 35.3 and 75.8 (sem 9.5) µg/L, respectively. These means were significantly different at p<.001. Medication of the trough-water supply with I tablets was an effective I supplement for dairy cows at pasture. The data suggest a water medication dose >60 mg I/cow/d to maintain PII >105 µg/L, or 60 mg/cow/d if a threshold >70 µg/L is acceptable

Table 19. For details of the trial, see <u>Aquadyne in the water supply for dairy cows</u>, above. Mean PII se and sem (µg/L) for dairy cows pre-, during (d7 to d28) and post- (d-7 and d-14) supplementation with Aquadyne tablets, supplying 0, 30 and 60 mg I/600 kg LW/d (treatments C, H and F, respectively) via the drinking water. (*=significant at p<.001).**

TR		Pre	d7	d14	d21	d28	d-7	d-14	Effect (On-Off)
C	X	19.75	20	22	17.1	16.4	17.4	17	0.4
	se	1.75	1.74	2.81	1.93	1.67	0.64	1.48	0.91
H	X	12.65	46.1	71.6	40.7	47.9	15.2	24.8	35.3
	se	0.84	3.73	21.09	4.21	8.73	1.07	2.7	7.62
F	X	15.25	102.6	95.5	102.8	75.4	19.7	22.8	75.8
	se	1.03	12.88	25.35	22.87	9.47	2.15	1.93	14.62
									sem 9.5***

3c. I supplementation of cattle via slow-release boluses (26)

Ionox (Animax / Bayer), is the only bolus available for long-term I supplementation for cattle. It is a new slow-release bolus for oral use in cattle, was developed in co-operation with Teagasc, Grange. The bolus was designed to remain in the reticulorumen during its period of trace element release; it contains 3500 mg I, 500 mg Se and 350 mg Co/bolus. Ionox contains no Cu; it has no value as a Cu supplement. Prototypes (Mark 1, 2 and 3), tested between 1993 and 1995, gave encouraging results but the duration of PII elevation after dosing was too short (27, 28, 29). The final version (Mark 4) was released on the Irish market in autumn 1996 and on the UK market in 1997.

(a) Ionox Irish controlled trial (Nov 95-Aug 96):

Steers (421 kg) were randomised to three groups of 7: Gp 0=no supplement; Gp 1=one Ionox bolus; Gp 2=two boluses. They were fed grass-silage + home-grown rolled barley low in I and Se for the first 4 months indoors. After that, their diet was grazed grass only. Heparinised blood was drawn for PII and glutathione peroxidase (GPx) assay on D0 (just pretrial) and on 8 occasions thereafter. Table 20 summarises the results. Control levels of PII and GPx, respectively, stayed very low and low-normal to marginal throughout. One bolus significantly increased PII and GPx for 23 weeks; two boluses maintained normal levels of PII and GPx for 23 and 33+ weeks, respectively.

(b) Ionox UK field trial 1997:

Blood from 5 treated and 5 control cows or adult heifers in each of 47 commercial UK herds was assayed for PII Pretrial and 1 month after dosing with one Ionox bolus. Table 21 summarises the results. Overall, Ionox increased PII levels by (mean+se) 117+10.7 µg/L relative to PII changes in the controls ($p<.001$).

Table 20. For details of the trial, see <u>Ionox Irish controlled trial (Nov 95-Aug 96)</u>, above. Treatment means for blood PII (µg/L) and GPx (iu/g Hb) for steers on 0, 1 and 2 Ionox boluses. Means with differing suffixes in the same column are significantly different.

Gp	Pre	d26	d61	d93	d119	d159	d181	d208	d236
PII									
0	15a	14a	23a	26a	15a	19a	21	20	10
1	16a	162b	124b	94b	63b	70b	40	32	9
2	16a	383c	280c	218c	160c	104c	25	25	9
Sig.	ns	***	***	***	***	***	ns	ns	ns
GPx									
0	48^a	42^a	41^a	52^a	42^a	50^a	49^a	54^a	45^a
1	57^a	59^b	69^b	75^b	68^b	72^b	65^a	66^a	63^b
2	57^a	56^b	78^b	87^c	84^b	89^b	89^b	89^b	69^b
Sig.	ns	*	***	***	**	**	***	***	**

Table 21. For details of the trial, see <u>Ionox UK field trial 1997</u>, above. Means and se pretrial (S0) and after 1 month (S1), mean change from pretrial value and se of change for blood PII, and net effect of treatment (µg/L) in control (untreated) and experimental (one bolus) cows in the UK field trial. (*** = significant at $p<.001$).

	Control cows			Treated cows			Net Effect
	S0	S1	Change	S0	S1	Change	
X	80.7	109.1	28.4	80.1	225.8	145.7	117.3
se	5.7	9.4	6.9	5.9	12.1	10.9	10.7
Sig.			***			***	***

(c) Ionox Irish ad-hoc observations 1997:

Blood from commercial herds assayed at Grange indicated that herds given Ionox 1-3 months before blood test had better PII levels than unsupplemented herds.

Overall, Ionox was an effective slow-release I and Se supplement. Assuming linear release over 28 weeks, mean release would be 18, 2.6 and 1.8 mg I, Se and Co/bolus/d respectively. This should suffice for yearling cattle on pastures that pose a risk of severe deficiency of I, Se or Co. If no other I, Se or Co supplements were given, adult cows would need 2-3 boluses every 5-6 months on similar high-risk pastures (26).

3d. I supplementation of cattle via skin application

PII response in steers to oral and skin applied I (9)

Changes in PII level in steers treated with I were examined in Friesian steers (n=6/treatment). In a randomised block experiment, steers were treated with 0 (C), 7 consecutive daily oral doses of 10 mg I/100 kg LW (D), or 70 mg I/100 kg LW applied to the skin of the flank fold on d1 (F). Blood samples were collected before initial treatment and 7 h later on d1, 3, 5 and 7, and once/d at intervals thereafter. Table 22 summarises the results. Mean PII before initial treatment was <20 µg/L (very low). Mean PII in C (control) remained very low to marginal throughout. Relative to C, peak PII for D occurred 7 h after dosing on d5 and did not differ significantly from C from d12 onwards. Relative to C, peak PII for F occurred 7 h after administration and did not differ significantly from C from d7 onwards. PII increased rapidly after oral- or skin-applied I. Daily oral dosing was more effective in maintaining PII than one skin application.

Table 22. For details of the trial, see PII response in steers to oral and skin applied I, above. Mean PII levels (μg/L) for samples taken between d1 and d57 from steers that had received 0 (C), 7 consecutive daily oral doses of 10 mg I/100 kg LW (D), or 70 mg I/100 kg LW applied to the skin of the flank fold on d1 (F).

Tr	Pre	d1 1615h	3	5	7	8	9	12	15	19	22	29	43	57
C	19	41	34	38	45	32	65	59	57	33	38	37	13	20
D	20	128	166	187	204	126	144	56	55	31	41	38	13	24
F	22	458	279	96	84	57	118	75	52	36	39	40	17	21
Sig	ns	***	***	***	***	***	**	ns	ns	ns	ns	ns	ns	ns

Underlined values are in the normal range, except 1615h sample (at 7 h after treatment on D1 (Gp F), which was very high.

Since the 1960s, some dairy farmers used to apply 5% tincture of I once/week to the thin skin in the pocket of the flank-fold as an I supplement for cows. The data above confirmed that weekly application of 70 mg I/100 kg LW to the flank fold effectively increases PII in the following week. However, as the handling-facilities on many suckler farms are often poor, that method is not easy to use in suckler cows.

DANI colleagues reported that some farmers in Northern Ireland apply 5% tincture of I weekly as an I supplement to the skin of the back, between the shoulder blades of suckler cows (Maurice McCoy and Frank Malone, personal communication). The method is practical, and the farmers claimed good results. In a simple uncontrolled test, we sprayed a solution of potassium iodide in water between the shoulder blades of a few cattle at Grange; this increased PII markedly. However, further work is needed to establish an optimum dose of KI for that use.

3e. Lipiodol injection as an I supplement for cattle

Injection of Lipiodol (an oil-based, 40% I compound) has been used by some workers to supply I in deficient herds. Two trials were done to assess the effect of Lipiodol on PII in cattle.

a. Lipiodol Trial 1 (9)

Changes in PII level were examined in a randomised block experiment in Friesian steers (n=6/treatment) treated with 0 (C), or intramuscular injection (1.1 ml/100 kg LW) of an oil-based I preparation (Lipiodol; 400 mg I/ml)) on d1 (L). Blood samples were collected before initial treatment and 7 h later on d1, 3, 5 and 7, and once/d at intervals thereafter. Table 23 summarises the results. Mean PII before initial treatment was <20 μg/L (very low). Mean PII in C (control) remained very low to marginal throughout. Lipiodol injection significantly increased PII between d3 and 43, and maintained normal PII between d6 and d36, but the effect was gone by d57 (9).

Table 23. For details of the trial, see Lipiodol Trial 1, above. Mean PII (μg/L) in control (C) and Lipiodol-injected (L) steers pretrial (Pre) and for 57d after the start of trial.

Tr	Pre	d1 1615h	3	5	7	8	9	12	15	19	22	29	43	57
C	19	41	34	38	45	32	65	59	57	33	38	37	13	20
L	18	40	63	87	125	105	140	144	166	162	128	166	60	17
Sig	ns	ns	*	***	***	***	**	***	***	***	***	***	***	ns

Underlined values are in the normal range.

b. Lipiodol Trial 2 (30)

As part of a larger trial (Oral I supplementation of beef steers, above), housed continental steers (mean circa 500 kg LW) were offered ad-libitum silage + 1.5 kg rolled barley twice/d. No mineral mixture was fed. Mean LW and PII levels in heparinised blood were established for each animal twice pretrial. Overall mean pretrial PII was 20 μg/L (very low). The steers were assigned at random to groups (n=6/group): Gp 1=Untreated controls and Gp 8=4 ml Lipiodol, 40% I in an oil base, injected once. Table 24 summarises the results. Lipiodol increased PII from d8 to d115 (p<.001) and maintained PII in the marginal or normal range for almost 90d (30).

In some foreign trials, Lipiodol injection of ewes in early pregnancy reduced the incidence of goitrous lambs. However, oil-based products are slow-acting and we are unaware of controlled work published in refereed scientific journals that shows that they prevent neonatal problems in cows. We are also aware of failure of I injection to prevent stillbirth in calves, which was controlled within days by oral I supplements (Rogers & Gately 1992).

Table 24. For details of the trial, see <u>Lipiodol Trial 2</u>, above. Mean PII (µg/L) in control (Gp 1) and Lipiodol-injected steers (Gp 8) pretrial (Pre) and for 126d after the start of trial.

Gp	Pre	8	15	22	29	36	43	50	57	64	67	70	73	76	80	86	95	105	115	126
1	20	19	20	13	10	10	7	5	8	16	11	12	12	12	9	13	15	17	24	44
8	23	115	121	102	84	88	79	76	84	100	122	135	117	109	90	74	66	72	63	57
sem	4.6	11	13	12	12	7	4	5	6	6	12	18	16	19	14	13	5	12	9	21
Pr<F	ns	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	ns

Underlined values are in the normal range.

After a lag phase of some days (trial 3e.a) Lipiodol significantly increased PII for 42d (trial 3e.a) to 90d (trial 3e.b) after injection in our trials. However it is not registered as a therapeutic agent on the veterinary product list and oral I supplements can maintain normal PII levels for a fraction of its price.

Lipiodol is not recommended as an I-supplement for cows because other methods are effective, faster acting and cheaper.

3f. I supplementation via periodic drenching

PII in steers after an I drench or I by continuous infusion (9)

Eight steers, confirmed to have very low PII status before the trial, were given silage + 3 kg barley/soya mixture in individual stalls. Each steer was assigned at random to one of 4 treatments (n=2 per treatment) X 3 test periods (each of 8d), with cyclic changeover of animals between treatments, after an interval of 21 or 15d respectively from the last dose of the previous period. The treatments were 1=No I (Control); 2=0.10 mg I/kg LW drenched once daily; 3=0.10 mg I/kg LW/d, drenched in two equal portions; 4=0.10 mg I/kg LW/d, infused continuously into the rumen. The I dose was given as a solution of potassium iodide, from d0-7 inclusive/period. Indwelling jugular catheters were used for collection of blood before the first treatment in each period (d0), at 0, 4, 8, 12, 16 and 20h on d1, 3 times on d2, 4 times on d7, 3 times on d8 and once on d10 and 13 of each period, giving 420 plasma samples for analysis. Table 25 summarises the results. PII increased markedly within 24h of oral drenching with I. Mean PII levels attained by drenching once or twice daily (Gps 2, 3), or by continuous infusion (Gp 4) were similar, except for an unexplained anomaly on d8. On withdrawal of I (afternoon of d7), PII rose (d8) and then fell rapidly, but did not reach control levels by 6d after withdrawal. PII levels

attained during dosing in Gps 2-4 were too high on d7 and 8. These levels were higher than levels attained in cows on similar doses, suggesting that an I supplement of 60 mg I/600 kg LW/d (as advised for cows) may be more than steers need.

Table 25. For details of the trial, see <u>PII in steers after an I drench or I by continuous infusion</u>, above. Mean PII ((µg/L) in steers (Gp 1 to 4) dosed orally with 0, or 0.10 (once, twice in two equal parts, or continuously infused into the rumen) mg I/kg LW/d, respectively.

		Days of dosing (1, 2, 7)			Days of no dosing (8, 10, 13)		
Gp	0 (Pre)	1	2	7	8	10	13
1	9.5	12.3	11.3	9.4	10.8	13.0	10.8
2	9.0	206.2	203.4	349.8	365.5	195.5	42.0
3	8.5	183.8	196.1	353.4	461.3	238.3	102.7
4	12.5	175.1	198.1	339.2	509.8	279.5	109.2
Sig.	ns	***	***	***	***	***	***

4. I LEVELS IN SAMPLES OF IRISH BULK-TANK MILK

Low I levels in bovine milk indicate I deficiency in the diet. Carryover of dietary I to milk is variable, but milk I levels increase with intake. High levels in milk may indicate excessive amounts of dietary I, or contamination of milk by I-based teat dips, or disinfectants on the farm, in transit to the milk depot, or during milk processing.

I in cattle feed is mainly iodide, absorbed more or less totally from all levels of the digestive tract. Very little I appears in faeces and that which does is organically bound. Other forms of inorganic I (for example iodates) are reduced to iodide before absorption. Iodinated amino acids are well absorbed as such, though slower than iodide. Ethylene-diamine-dihydro-iodide (EDDI) is very highly absorbed. Recycling (secretion in saliva, gastric juices etc) is a means of conserving I. Urine is the main route of I excretion and increasing levels of I are secreted in milk with increasing inputs of I (Underwood 1962).

However, milk products supply up to 50% or more of human dietary I (as iodide) intake. High I intakes can cause thyrotoxicosis in humans. The threat is greatest to infants fed large amounts of milk powder with excessive levels of I. The American NRC recommends a maximum of 1000 µg I/d as safe for adult humans. From pre-1970 to 1978, milk I levels in American bulk-tanks increased so that a daily intake of 500-1000 ml milk from some farms (1000-2000 µg/L) and 125-500 ml of heavily contaminated milk (2000-8000 µg/L) would exceed the safe human adult dose (Hemken 1979).

There is great variation in the breakpoints used by different authors to assess I status in bovine milk. As an index of bovine I supply, the Grange Labs use:

MI level (µg/L)	<25	25- 38	39- 50	51-300	301-400	>400
MI Status	Very Low	Low	Marginal	Normal	High	Very high

Between September 1992 and October 1995, 69 samples of milk from farm bulk-tanks were tested for milk I levels. Some samples were grossly deficient in I; others were from herds on an I supplement. The mean milk I value was 139 (range 2-435, sd 108) µg I/L. On average, adults would have to drink >7 l milk/d to exceed the safe level of I from that source. The data indicate no serious national problem with I levels in Irish bulk-tank milk.

Until now, Teagasc has advised a maximum supplement of 60 mg I/cow/d but EU Feed Regulations allow up to 165 mg/cow/d. Contamination by I in teat dips and disinfectants, or from excessive use of I supplements in dairy herds, can increase milk I levels. I can also enter milk after the bulk-tank. Non-dietary I (teat dips, disinfectants, post-farm I contamination) is a greater source of I in milk than is dietary I. Hemken (1979) cites studies by Connally (1971), Joerin & Bowering (1972), Iwarsson & Ekman (1973), Uusl Rauva et al (1974) and Dunsmore (1976) that suggest mean increases of MI due to use of iodophors of 35-390 mg/L between farms or 174-285 mg/L between studies.

On grounds of herd health and human health, there is a case for monitoring larger numbers of bulk-tank samples and, especially, samples of milk at retail sales outlets (33).

5. OVERALL SUMMARY OF THE DOSE-RESPONSE DATA

In all, mean bovine dose-responses in PII to known input of oral I supplements were available for 28 data sets. Table 26 summarises the bovine I dose-response data. Figures 1, 2 and 3 summarise the dose-response data graphically (6 data sets for dairy cows, 12 data sets for beef calves, heifers and cows, and 10 data sets for steers). The following table summarises the supplementary I inputs needed

to ensure mean PII increases of 100 µg/L above those of unsupplemented control animals:

Animal type	Regression (b) value from all data sets in the equation: PII increase = I dose*b:	Supplement (mg I/100 kg LW) needed
Dairy cows	b=8.482 (r^2=.414)	11.79
Beef calves, heifers and cows	b=21.217 (r^2=.188)	4.71
Steers	b=15.653 (r^2=.588)	6.39

Although the PII response correlated significantly with the I dose, the error of the estimate was wide, especially in the case of the beef calves, heifers and cows (in which the r2 was lowest).

Figure 1. Dose-response data for dairy cows (6 data sets)

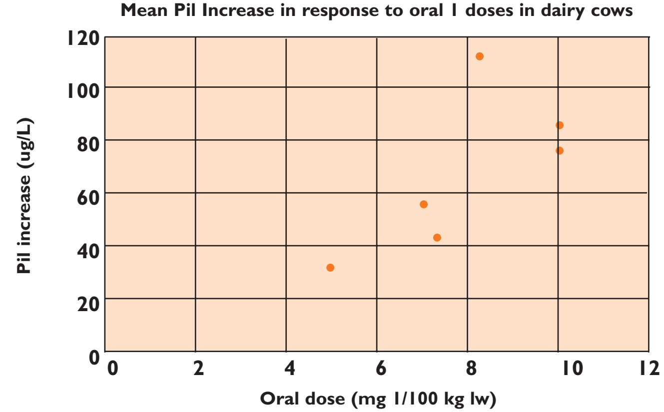

Figure 2. Dose-response data for beef calves, heifers and cows (12 data sets)

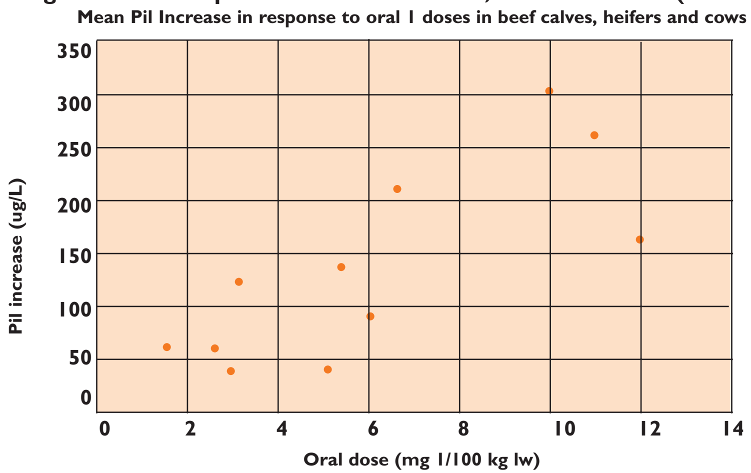

Figure 3. Dose-response data for steers (10 data sets)

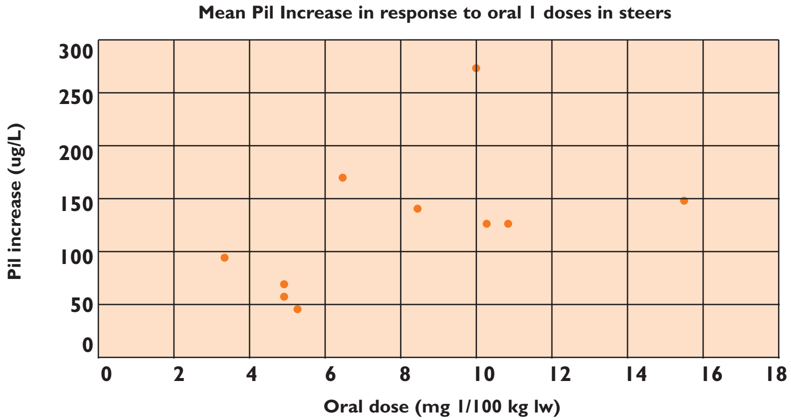

Table 26. Summary of mean PII increases (µg/L) above control changes in response to known oral supplements of I.

Animal type	Trial	Oral I dose (mg/100 kg LW/d), assuming cows at 600 kg	PII increase (µg/L) above control changes
Cows, dairy	Aquadyne (25)	5.000	35
Cows, dairy	Waterford 1994 (12)	7.167	57
Cows, dairy	NCF 1992 (10)	7.500	42
Cows, dairy	I via silage (14)	8.333	113
Cows, dairy	Aquadyne (25)	10.000	75
Cows, dairy	NCF 1993 (11)	10.000	82
Calves 4 mo suckling	Aquadyne in water (24)	5.000	41
Heifers, beef	Oral I (17)	1.667	60
Heifers, beef	Oral I (17)	3.333	117
Heifers, beef	Oral I (17)	6.667	212
Heifers, beef	Oral I (17)	10.000	304
Cows, beef, dry	Oral I (18)	3.000	43
Cows, beef, dry	Oral I (18)	6.000	94
Cows, beef, dry	Oral I (18)	12.000	159
Cows, beef, dry & suckling	I via silage (13)	2.667	63
Cows, beef, dry & suckling	I via silage (13)	5.333	136
Cows, beef, dry & suckling	I via silage (13)	10.833	260
Cows, beef, suckling	Aquadyne (24)	5.000	43
Steers	Oral I (16)	3.333	94
Steers CoX	Aquadyne (23)	5.000	67
Steers Fr	Aquadyne (23)	5.000	60
Steers Fr	Flowtrace (22)	5.167	48
Steers	Oral I (16)	6.667	166
Steers	Oral I (16)	10.000	273
Steers	Drench v infusion (9)	10.000	272
Steers Fr	Flowtrace (22)	10.333	115
Steers	Diurnal PII pattern (7)	11.000	116
Steers Fr	Flowtrace (22)	15.500	149

6. OVERALL CONCLUSIONS ON OPTIMAL I SUPPLEMENTS FROM THE PII DOSE-RESPONSE DATA

To maintain PII in the lower end of the normal range, dairy cows need 1.85 times the I supplement of steers/100 kg LW. In turn, steers need 1.36 times that of beef calves, heifers and cows/100 kg LW.

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PII REFERENCES & PUBLICATIONS

1. **Aumont G & Tressol JC (1987)** Rapid method for the direct determination of inorganic iodine in plasma using ion-exchange chromatography and the Sandell and Kolthoff reaction. Analyst 112: 6, 875-878.
2. **Rogers PAM (1991)** Iodine deficiency in cattle. Paper to British Cattle Veterinary Association Meeting, Kinsale, October 18.
3. **Rogers PAM (1989)** Prevalence of iodine deficiency in Irish herds. Annual Research Report, Grange Research Centre 111 and Rogers PAM (1990) Ibid. Annual Research Report, Grange Research Centre 105.
4. **Rogers PAM (1989)** Composition of cattle and sheep mineral/vitamin mixes on the Irish market. Annual Research Report, Grange Research Centre, p115) and Rogers PAM (1990) The Cost and Composition of Cattle and Sheep Mineral/Vitamin Mixes on the Irish Market. Teagasc Bulletin. Issued to Nutritionists in the Mineral Mix/Feed Compounding trade, 18pp.
5. **Rogers PAM (1991-1992)** Specialist investigation and advisory service. Annual Research Report, Grange Research Centre 214-215.
6. **Rogers PAM & Murphy WE (1999)** Levels of Dry Matter, Major Elements and Trace Elements in Irish Grass, Silage and Hay. Grange Research Centre Webpage at http://www.teagasc.ie/grange/0forage.htm
7. **Rogers PAM, Larkin JA & Moloney AP (1992)** Diurnal pattern in bovine PII levels after an oral dose of I. Annual Research Report, Grange Research Centre 218.
8. **Rogers PAM & Larkin JA (1992)** PII levels in horses. Annual Research Report, Grange Research Centre 219-220.
9. **Rogers PAM, Larkin JA & Moloney AP (1992)** PII status in steers treated with I. Annual Research Report, Grange Research Centre 220.

10 **Rogers PAM (1992)** Effect of a mineralised summer dairy nut on copper, selenium and iodine status of dairy herds in Connaught. Annual Research Report, Grange Research Centre 220 and Rogers PAM (1992) Confidential Report to NCF on the 1992 Trial. Also: Rogers PAM (1992) Effect of mineralised summer dairy nut on copper, selenium and iodine status of dairy herds in Connaught. Report to North Connaught Farmers Co-operative, Ballaghaderreen, Co. Roscommon; Rogers PAM (1992) Mineral supplementation of cattle in Connaught. North Connaught Farmers Newsletter, March.

11.**Rogers PAM (1993)** Effect of mineralised summer dairy nut on copper, selenium and iodine status of dairy herds in Connaught. Annual Research Report, Grange Research Centre 7 and Rogers PAM (1993) Confidential Report to NCF on the 1993 Trial.

12.**Rogers PAM (1994)** Effect of mineralised summer dairy nut on copper, selenium and I status of dairy herds. Annual Research Report, Grange Research Centre 53.

13. **Rogers PAM & Drennan MJ (1995)** Oral I supplementation of suckler cows. Annual Research Report, Grange Research Centre 63-64.
14. **Mee JF, Rogers PAM & O'Farrell KJ (1995)** Effect of feeding a mineral-vitamin supplement before calving on the calving performance of a trace element-deficient dairy herd. Vet Rec 137, 508-512. Also: Mee JF, Rogers PAM & O'Farrell KJ (1994) Effect of precalving feeding of a mineral-vitamin supplement on calving performance in a trace element-deficient dairy herd. Association of Vet Teachers & Research Workers, 31st Spring Scientific Meeting, Abstract.
15. **Rogers PAM & O'Kiely P (1994)** Effects on trace element status in cattle of adding molasses with trace elements to grass at ensiling. Annual Research Report, Grange Research Centre 54.
16. **Rogers PAM & O'Riordan EG (1996)** Oral I supplementation of beef steers. Annual Research Report, Grange Research Centre 38-39.
17. **Rogers PAM & O'Kiely P (1996)** Oral I supplementation of beef heifers. Annual Research Report, Grange Research Centre 39.
18. **Rogers PAM & Drennan MJ (1994)** Oral I supplementation of suckler cows. Annual Research Report, Grange Research Centre, 52.
19. **Rogers, PAM (1997)** International Questionnaire on Mineral and Vitamin Supplementation of Dairy Cows. Annual Research Report, Grange Research Centre 30-31.
20. **Rogers PAM, Poole DBR & Drennan MJ (1989)** A Test of Dosatron water medication pumps. Annual Research Report, Grange Research Centre 113.
21. **Rogers PAM (1996)** Speed of release of I from Aquadyne and Aquasel tablets after immersion in water. Annual Research Report, Grange Research Centre 40.
22. **Rogers (1990)** Water medication with chelated trace elements (Cu, Se, Co, I): An initial controlled assessment of efficacy and safety in cattle. Confidential report to funding company. . Annual Research Report, Grange Research Centre 104-105. Also: Rogers PAM, Mee JF & Drennan MJ (1998) Iodine supplementation of cows and calves via trough-water. Irish J of Agric Research 37:1; 114 and Rogers PAM, Mee JF & Drennan MJ (1998) Iodine supplementation of cows and calves via trough-water. Proc. Agric Research Forum, March 19-20 1998, Agric Faculty, UCD, Belfield, p97-98.
23. **Rogers PAM & Keane MG (1996)** Water medication as an I supplement for cattle. Annual Research Report, Grange Research Centre 41-42. Also: Rogers PAM & Keane MG (1998) Iodine via the water supply: 1: Effect on PII in steers. World Cattle Congress, Sydney, Jul 4-10.
24. **Rogers PAM & Drennan MJ (1996)** Water medication as a means of supplementing suckler cows and calves with I. Annual Research Report, Grange Research Centre 42-43. Also: Rogers PAM, Mee JF & Drennan MJ

(1998) Iodine via the water supply: 2: Effect on PII in cows and calves. World Cattle Congress, Sydney, Jul 4-10.

25. **Mee JF & Rogers PAM (1997)** Water medication as a means of supplementing dairy cows with I. Annual Research Report, Grange Research Centre 30. Also: Rogers PAM, Mee JF & Drennan MJ (1998) Iodine via the water supply: 2: Effect on PII in cows and calves. World Cattle Congress, Sydney, Jul 4-10.
26. **Rogers PAM, Lynch PJ, Porter WL & Bell GD (1997)** Effect of a slow-release bolus on PII in cows in commercial UK herds. Annual Research Report, Grange Research Centre 30. Also: Rogers PAM, Lynch PJ, Porter WL & Bell GD (1998) A slow-release iodine, selenium and cobalt cattle bolus. Cattle Practice 6(Apr): 129-132; British Cattle Vet Association, Exeter, England, Apr 22-23 and World Cattle Congress, Sydney, Jul 4-10.
27. **Rogers PAM (1993)** Slow-release I supplementation of suckler calves via a slow-release bolus. Annual Research Report, Grange Research Centre 5.
28. **Rogers PAM (1994)** Slow-release I supplementation of suckler calves via a bolus. Annual Research Report, Grange Research Centre 52-53 and Slow-release I and Se supplementation of cattle via a bolus. Ibid 53.
29. **Rogers PAM & Drennan MJ (1995)** Supplementation of cattle with I via a slow-release bolus. Annual Research Report, Grange Research Centre 64 and Supplementation of cattle with I and Se via a slow-release bolus. Ibid 64.
30. **Rogers PAM & O'Riordan EG (1996)** Injection of Lipiodol as an I Supplement for Beef Cattle. Annual Research Report, Grange Research Centre 38-39.
31. **Rogers PAM, Larkin JA & Moloney AP (1993)** PII status in donkeys treated with 0.05-0.20 mg I/kg LW. Annual Research Report, Grange Research Centre 5-6.
32. **Rogers PAM & Hanrahan JP (1995)** Effects of an oral I drench on PII in sheep. Annual Research Report, Grange Research Centre 64.
33. **Rogers PAM (1994)** I levels in samples of Irish bulk-tank milk. Annual Research Report, Grange Research Centre 53-54; Rogers PAM (1995) I levels in samples of Irish bulk-tank milk. Ibid 65; Rogers PAM (1999) Dietary I supplementation in cattle and its effects on I levels in bulk-tank milk. Memo, 5 Apr 1999, to Dr. Tom Keating, Animal Feedstuffs Inspectorate, Dept. Agric & Food, Kildare St., Dublin 2.

This project generated a further 38 popular publications - details are available on request.