Salt spreading trials on the TRL Track - Interim Report 2

by M H Burtwell and M Zohrabi

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TRL Limited

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		Highway Authority Consortium
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Project Reference: National Salt Spreading Research Group (NSSRG)

Project Sponsor: Roger Williams (Chairman of the NSSRG)

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EXECUTIVE SUMMARY

Scope of the project

The National Salt Spreading Research Group (NSSRG) commissioned TRL Limited in 2001 to undertake a four-year research programme into spreader performance under controlled conditions on the TRL research track in Berkshire. The aims of the research were to:

- Confirm the spread rate and distribution patterns of dry and pre-wetted salting and brine only application, through dynamic performance testing.
- Seek assurance that different manufacturers’ distribution systems are capable of delivering the required performance standards, in terms of required coverage and rate of spread of salt in dry, pre-wetted forms and brine only application.
- Develop and evaluate techniques for the measurement of residual salt levels.
- Determine the optimum salt grade, purity and moisture content for dry and pre-wetted salt applications.
- Determine optimum rates of spread for different salting techniques.

In order to provide feedback to members of the Research Group, reports were planned for delivery at two interim stages. Interim Report 1 – Version 2 (Burtwell and Zohrabi, 2004a) describes the first six performance trials carried out on the TRL research track. This report, Interim Report 2, describes a further seven performance trials completed in Stage 2.

Summary

Six performance trials were carried out on four spreaders with two grades of salt, 3mm and 6.3mm rock salts, using dry and pre-wetted salting techniques in asymmetric and symmetric modes. Another trial was carried out on a brine only spreader in asymmetric mode. The dry testing was carried out according to BS 1622 (BSI, 1989). This standard was slightly modified to accommodate the pre-wetting and brine only techniques because no national standard is available for these types of spreading. The following factors were investigated:

- Achieved discharge rate
- Achieved spread rate in the main target area and wastage to the roadside verge
- Effect of salt grading and moisture content on the salt distribution
- Performance of the spreading equipment, including transverse and longitudinal snaking effects

In each trial, the distribution of salt within the target area and the wastage to the road edge was dependent on the calibration of the spreader, and the type, moisture content and condition of the salt in the hopper. The individual authorities that supplied the spreaders for calibration determined the spreader settings and the type of de-icing products to be used. Client representatives and TRL were present on site and checked visually, as far as possible, that each spreader was discharging salt satisfactorily prior to individual trials. It should be noted that no inference should be made about the performance of the spreaders with different settings or de-icers to those used in these trials.

The main conclusions that can be drawn for the various parameters are:

1. The amount of salt discharged by the Econ Zero C Mk 4 – 2002 model spreader during 2-lane dry salting with 6.3mm salt was well below the target level when the hopper was full, possibly because the salt was consolidated in the hopper. When the hopper was 10 per cent full, and the target spread rate was $10g/m^2$ in asymmetric mode, the spreader performed well , but under-salted when the spread rate was $20g/m^2$ where there was significant wastage. During symmetric spreading, there was considerable wastage at both spread rates, and lane 2 was significantly under-salted.

2. The Econ Zero C Mk 4 -2002 model spreader consistently under-salted the target area during 2-lane asymmetric pre-wetted salting with 3mm salt. The salt discharged during symmetric spreading was significantly above the target level, but the target area was under-salted in most tests, and there was considerable wastage.

3. The Epoke Sirius SH3500 spreader consistently under-salted the target area during 2-lane asymmetric pre-wetted salting with 6.3mm salt, and there was significant wastage. The spreader performed well during symmetric spreading when the target spread rate was $10g/m^2$, but performed poorly when the spread rate was $20g/m^2$.

4. The Epoke Combi Sirius S4502 spreader performed well during asymmetric brine spreading when the target spread rate was $12.1g/m^2$. There was under-salting at three other spread rates up to $42.4g/m^2$. There was significant wastage at most spread rates.

5. A Schmidt spreader, modified so the direction of the spinner disk was reversed, over-salted lane 1 and the hard shoulder during 3-lane asymmetric dry salting with 6.3mm salt. Lane 2 was sometimes over- and sometimes under-salted, whereas lane 3 was always under-salted. During symmetric spreading, lane 1 and 2 were over-salted, and lane 3 and the hard shoulder were under-salted, the hard shoulder the more so. The wastage was low.

6. The performance of the modified Schmidt spreader was similar during 3-lane pre-wetted salt. Lane 1 and the hard shoulder were over-salted during asymmetric spreading, and lane 2 was under-salted. Lanes 1 and 2 were over-salted during symmetric spreading, and lane 3 was under-salted. In both spreading modes, the hard shoulder was under-salted and the wastage was low.

7. During 2-lane asymmetric dry salting with 6.3mm salt, the Giletta 80501D spreader under-salted lane 1 and delivered near to or above the target level to lane 2, but about half the salt discharged was wasted.

8. The moisture content of the salt had a significant effect on the salt distribution profile, particularly when higher than 4 per cent at the time of spreading. Excessive moisture content causes larger salt grains to travel further and the fines to concentrate at the rear of the spreader.

Implementation

Evidence from the TRL research track trials will assist Local Highway Authorities with operational decisions concerning the set up and performance of their spreaders on their roads during dry salting, pre-wetted salting and brine only spreading.

Full details of each spreader's performance will be included in the Final Report which is due at the end of the research programme in December 2004. Five workshops are planned at different locations across the UK to review the outcome of the four-year research programme and to discuss a draft Business Plan for the next stage of the research.

ABSTRACT

This report describes seven performance trials on TRL's research track to determine the efficacy of spreading pre-wetted salt and brine compared with that of dry rock salt. Two grades of salt, 6.3mm and 3mm rock salt, were distributed from four types of spreader. The brine was distributed from a brine only spreader. The pre-wetted salting involved the use of dry rock salt plus a 23.5 per cent solution of brine at a ratio of 70:30 dry rock salt to brine solution. The testing was carried out in accordance with a method based on BS 1622 (BSI, 1989). The performance of the different spreaders using the various grades of salt was assessed with respect to salt discharge rate, achieved spread rate within the target area, wastage to the roadside edge, transverse and longitudinal snaking, the effect of salt grain size and moisture content on the salt distribution, wind speed and direction on the salt distribution profile, during both symmetric and asymmetric spreading. The test results indicated clear patterns with respect to some of the parameters investigated.

1 INTRODUCTION

Recent estimates have shown that £168 million was spent in 2001-02 in keeping the Local Authority highways in the UK free of frost, ice and snow (Thornes, 2003). In addition, approximately £51 million was spent for winter maintenance of the motorway and trunk road network in the UK[1] in the same period. Traditionally, this has been achieved by the application of dry rock salt at or very close to its natural moisture content of about 3.5 per cent. In the UK, basic application methods for salting have changed little during the last two decades. However, more recently, salting techniques developed in continental Europe and North America have received increasing attention from highway winter maintenance practitioners in the UK. These techniques utilise the pre-wetting of salt, in which high purity salt is combined with saturated brine at the spreading mechanism.

The National Salt Spreading Research Group (NSSRG) commissioned TRL Limited in 2001 to undertake a four-year research programme into spreader performance under controlled conditions on the TRL research track in Berkshire. In order to provide feedback to the members of the research group on the results of the research, two interim reports were planned. Interim Report 1 (Burtwell and Zohrabi, 2004a) describes six performance trials carried out on the TRL research track under controlled conditions from May 2001 to April 2002. Four different spreaders were used to distribute dry and pre-wetted salt asymmetrically and symmetrically to the surface of the test site.

Experience gained from these trials was then applied to selected live road trials undertaken by various members of the NSSRG Research Group. These road trials were designed to corroborate, or otherwise, the results obtained from the performance trials. The outcome of all the trials has enabled direct comparisons to be made between dry salting, pre-wetted salting and brine application. The results are given in the Final Phase 1 report (Burtwell and Zohrabi, 2004b).

This report, Interim Report 2, describes a further seven performance trials carried out on the TRL research track from November 2002 to April 2004. The objectives of these Stage 2 trials were similar to those discussed in Interim Report 1 (Burtwell and Zohrabi, 2004a). The trials are discussed in detail below with reference to the following variables:

- Achieved discharge rate
- Achieved spread rate in the main target area and wastage to the roadside verge
- Effect of salt grading and moisture content on the salt distribution
- Performance of the spreading equipment, including transverse and longitudinal snaking effects

Copies of all the reports are available to members on the NSSRG web site - http://www.trl.co.uk/nssrg

[1] Total sum includes costs for England, Wales, Scotland and Northern Ireland.

2 PERFORMANCE TRIALS

2.1 Spreading equipment

Details of the spreaders used in the performance trials are also shown in Table 1.

The Epoke Combi-spreader, used in trial 4, was a modified version of the conventional Epoke spreader with a spray bar fitted instead of the standard pre-wetting system for brine spreading in asymmetric mode.

The Modified Schmidt spreader used in trials 5 and 6 was the same type as the spreader tested in Stage 1. However, after the trial in Stage 1 it was thought that the clockwise rotation of the spinner disc may have been responsible for the under-salting of lane 3 during 3-lane spreading. This direction is used for spreading on the Continental Europe road system when the salt is spread from the slow lane on the right of the carriageway. Therefore, for the trials in stage 2, the manufacturer modified the spreader so the spinner rotated anti-clockwise. A road trial was carried out on the A48(M) using the same modified spreader (Burtwell and Zohrabi, 2004b).

The Giletta spreader, used in trial 7, was a conventional dry salt spreader employed by the Scottish Executive on its Motorways and Trunk Road network.

The individual authorities that supplied the spreaders for calibration determined the spreader settings and the type of de-icing products to be used. Client representatives and TRL were present and checked visually, as far as possible, that each spreader was discharging salt satisfactorily prior to individual trials. It should be noted that no inference should be made about the performance of the spreaders with different settings or de-icers to those used in these trials.

2.2 Grading of salt

The particle size distributions of the different salts used in the trials are shown in Figure 1. The grading curves for all the salts are within the limits given in BS 3247 (BSI, 1991). The performance trial involving the 3mm rock salt from Salinity (Germany) took place over two different time periods using salt from the same stockpile. The other trials were carried out over two consecutive days, those with the hopper full on day one of the trial, and those with the hopper 10 per cent full on day two.

2.3 Test method

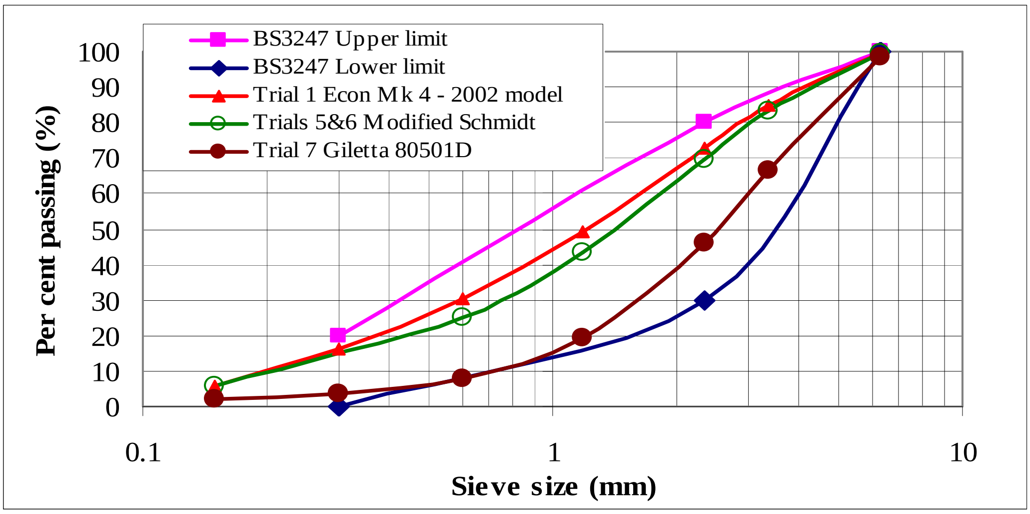
The performance trials were carried out on the TRL research track using the methodology described in Interim Stage 1 Report (Burtwell and Zohrabi, 2004). Details of the trials carried out in Stage 2 are shown in Table 1.

During brine spreading trial, the spreader operated only asymmetric operation, so the eight test combinations included repeat test runs of the asymmetric permutations at four different spread rates, as shown in Table 2.

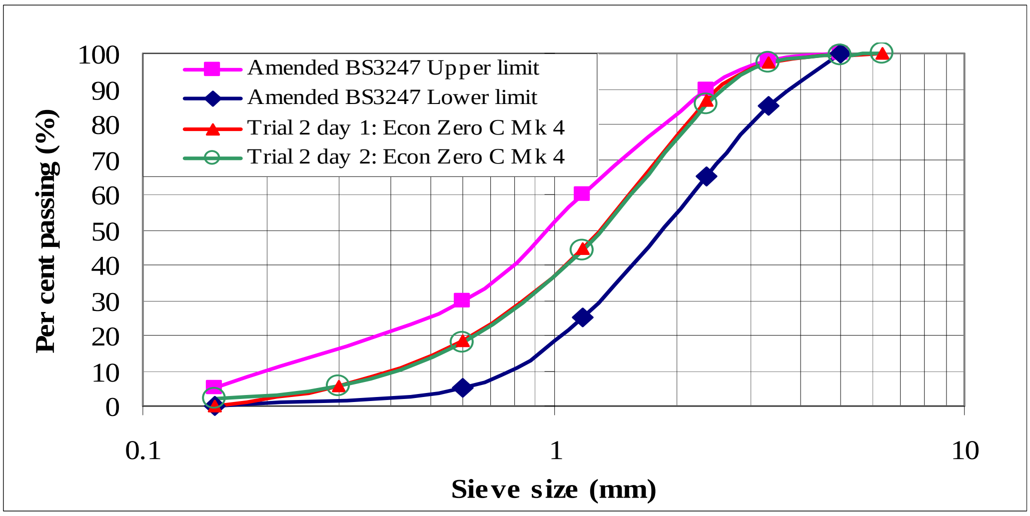
Table 1. Summary of trials carried out in stage 2

Trial No.	Spreader type	Grade of salt used	Moisture content (%)	Type of salting	Wind speed (mph)	Wind direction	Lane coverage Ω
1	Econ $6m^3$ Zero C Mk 4 Pre wet Permanently mounted bulk spreader – 2002 model on Leyland DAF Chassis	6.3mm, rock (Salt Union)	1.59	Dry	1 – 3	Both days	2-Lanes
2		3mm, rock (Salinity from Germany)	1.72	Pre-wetted	5 – 11 (day 1)* 1 – 2 (day 2)**	Day 1 Day 2	2-Lanes
3	Epoke Sirius SH3500	6.3mm, rock (Salinity from Germany)	5.41	Pre-wetted	1 – 2 (day 1)* 1 – 6 (day 2)**	Day 1 Day 2	2-Lanes
4	Epoke Combi Sirius S4502	Brine only	-	Brine	0 – 2	Both days	2-Lanes
5	Modified Schmidt Stratos B90-42-VALN5Z Modified Schmidt [γ]	6.3mm, rock (Salt Union)	1.93	Dry	1 – 4 (day 1)[Ψ] 2 – 5 (day 2)[ζ]	Day 1 Day 2	3-Lanes + hard shoulde r
6		6.3mm, rock (Salt Union)	1.93	Pre-wetted	1 – 3 (day 1)[Ψ] 2 – 5 (day 2)[ζ]	Day 1 Day 2	3-Lanes + hard shoulde r
7	Giletta 80501D 9.6 cu m dedicated spreader mounted on Mercedes 331AK 6x6 chassis	6.3mm, rock (Moroccan Bröste)	6.42	Dry	1 – 3	Both days	2-Lanes

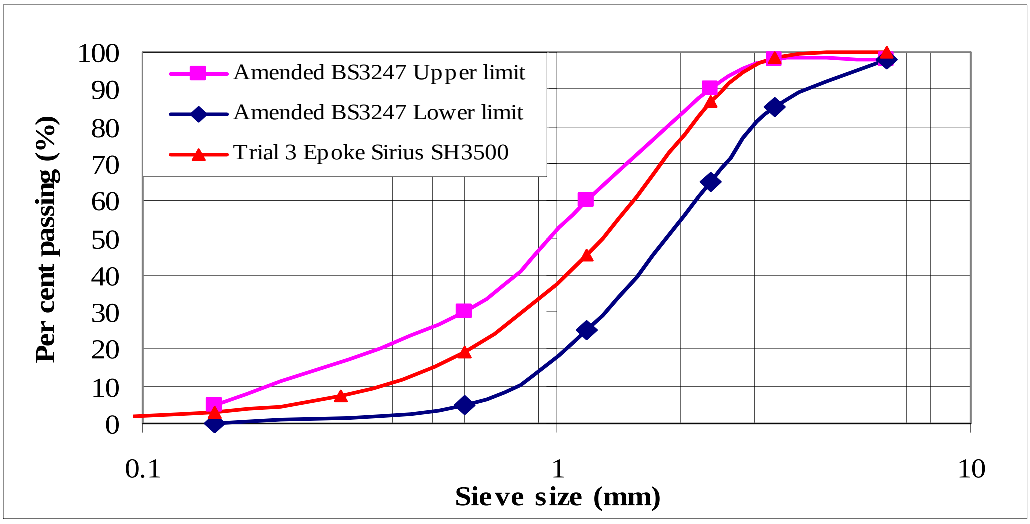
* Hopper full
** Hopper 10 per cent full
Ψ Asymmetric spreading
ζ Symmetric spreading
Ω The spreader travelled from north to south, i.e. ↓
γ Direction of spinner disc reversed



a) 6.3mm rock salt used in dry salting trials 1 and 5 (Salt Union), pre-wetted salting trial 6 (Salt Union) and dry salting trial 7 (Moroccan Bröste)



b) 3mm rock salt used in pre-wetted salting trial 2 (Salinity (Germany))



c) 6.3mm rock salt used in pre-wetted salting trial 3 (Salinity (Germany))

Figure 1. Grading of the different salts used in the performance trials

Table 2. Permutations for asymmetric brine spreading

Run Number	Spread rate	
	(ml/m^2)	(g/m^2)*
1	10	12.1
2 (repeat)	10	12.1
3	19	23.0
4 (repeat)	19	23.0
5	27	32.7
6 (repeat)	27	32.7
7	35	42.4
8 (repeat)	35	42.4

* based on a brine density of 1.21g/cm^3

As in the Stage 1 trials, the effect of grain size on the salt distribution profiles was determined by grading the salt scattered across the different areas of the road surface. In Stage 2, the dry salt was spread at a rate of 40 g/m^2 in asymmetric mode, whereas in Stage 1 it was spread at 20 g/m^2.

2.4 Overall salt discharge rate

In order to check the static calibration of spreaders [see BS 1622 (BSI, 1989)] against their dynamic calibration, an attempt has been made to quantify the total quantity of salt leaving the spreader against the specified target rate as set on the spreader control box. For this purpose, the quantity of salt discharged over the test strips was calculated as a percentage of the salt needed to cover the target area at the target spread rate. The width of the target area was taken as the spread width setting on the spreader rather than the 8m spread width specified in BS1622 (BSI, 1992)).

The discharge rate during 2-lane spreading was calculated from the following equation (see Figure 3):

$$\text{Discharge rate (\%)} = \frac{\text{total salt within 1m x 15m area}}{\text{target quantity of salt within (1m x 2-lane width) area}} \text{x100} \qquad (1)$$

The discharge rate during 3-lane spreading (by the Epoke spreader) was calculated from the following equation:

$$\text{Discharge rate (\%)} = \frac{\text{total salt within 1m x 15m area}}{\text{target quantity of salt within (1m x 3-lane width) area}} \text{x100} \qquad (2)$$

Both Equations (1) and (2) assume that no salt was distributed beyond the 15m test area.

When the hard shoulder was included within 3-lane operation (Tests 5 and 6 using Schmidt spreader), Equation (2) was adjusted to:

$$\text{Discharge rate (\%)} = \frac{\text{total salt within 1m x 15m area}}{\text{target quantity of salt within (1m x 3-lane + hard shoulder width) area}} \text{x100} \qquad (3)$$

The salt discharged in the performance trials is shown in Table 3. It was dependent on the mode of symmetry and the amount of salt in the hopper.

Table 3. Overall discharged salt against the specified target rate

Trial No.	Spreader type	No. of lanes (target spread width, m)	Type of salting	Quantity of salt discharged as percentage of the target quantity (%)			
				Asymmetric		Symmetric	
				Hopper full	Hopper 10 per cent full	Hopper full	Hopper 10 per cent full
1	Econ Zero C Mk 4 – 2002 model	2-lane (6.0)	Dry (10g/m^2)	47	145	78	134
			Dry (20g/m^2)	41	91	72	107
2		2-lane (6.0)	Pre-wetted (10g/m^2)	88	52	161	127
			Pre-wetted (20g/m^2)	96	83	131	124
3	Epoke Sirius SH3500	2-lane (7.0)	Pre-wetted (10g/m^2)	49^{ζ}	79^{ζ}	117^{ζ}	142^{ζ}
			Pre-wetted (20g/m^2)	42^{ζ}	67^{ζ}	73^{ζ}	97^{ζ}
4	Epoke Combi Sirius S4502	2-lane (7.0)	Brine (12.1g/m^2)	133/136*		NA**	
			Brine (23.0g/m^2)	79/103*			
			Brine (32.7g/m^2)	110/90*			
			Brine (42.4g/m^2)	90/74*			
5	Modified Schmidt	3-lane + HS (12.0)	Dry (10g/m^2)	145^{Ψ}		129^{Ψ}	
			Dry (20g/m^2)	100^{Ψ}		111^{Ψ}	
6			Pre-wetted (10g/m^2)	101^{Ψ}		161^{Ψ}	
			Pre-wetted (20g/m^2)	82^{Ψ}		87^{Ψ}	
7	Giletta 80501D	2-lane (6.0)	Dry (10g/m^2)	115^{β}	174^{β}	Not practised in Scotland	
			Dry (20g/m^2)	158^{β}	163^{β}		

* Based on duplicate tests at four discharge rates (10, 19, 27 and 35 ml/m^2). Spreading carried out at a constant pressure so the quantity of brine in the tank did not affect the discharge rate.
** Not applicable - symmetric spreading not possible with the spreader
Ψ Trials carried out with the hopper one-third full
ζ Possible salt consolidation in the hopper due to the spreader travelling a long distance with the salt
β Based on average of four results for each amount of salt in the hopper (2 at 10g/m^2 and 2 at 20g/m^2)

2.4.1 Econ Zero C Mk 4 – 2002 model (dry salting with 6.3mm salt)

The amount of salt discharged was, on average, 96 and 106 per cent, respectively, of the target level during asymmetric and symmetric spreading at 10g/m^2. When the target spread rate was 20g/m^2, the salt discharged was, on average, 66 and 90 per cent, respectively, of the target. Much more salt was discharged when the hopper was 10 per cent full than when it was full. This may have been caused by the salt moisture content being low (1.6 per cent). It may also indicate turbulence at the rear of the spreader or salt consolidation within the load that prevented the full salt discharge when the hopper was full.

2.4.2 Econ Zero C Mk 4 – 2002 model (pre-wetted salting with 3mm salt)

The amount of salt discharged was, on average, 70 and 144 per cent of the target during asymmetric and symmetric spreading at 10g/m^2. The percentages were 89 and 128 per cent, respectively, when the target spread rate was 20g/m^2. At both spread rates and in both spreading modes, more salt was discharged when the hopper was full than when it was 10 per cent full. The effect of the hopper load on the amount of salt discharged was greatest when the target spread rate was $10g/m^2$.

The two salts used for the dry and pre-wetted salting were of different origin and grading, although their moisture contents were similar. The 6.3mm rock salt used in dry salting contained a large amount of fines (i.e. 17 per cent finer than 0.3mm). The 3mm imported rock salt used in the pre-wetted salting had a uniform size with less fines content (i.e. seven per cent finer than 0.3mm). Therefore, the grading of the salts may have been a factor in the performance of the spreader.

2.4.3 Epoke Sirius SH3500 (pre-wetted salting with 6.3mm salt)

The spread width was 7m, the same width used for dry salting in stage 1. The amount of salt discharged was, on average, 64 and 130 per cent, respectively, of the target values during asymmetric and symmetric spreading at $10g/m^2$. The percentages were, on average, 54 and 85 per cent, respectively, when the target spread rate was $20g/m^2$. More salt was discharged when the hopper was 10 per cent full than when it was full.

Following a detailed assessment of the spreader settings, Lincolnshire County Council found that the spinner was set to a rate of 80 revolutions per minute – the setting usually recommended by the manufacturer for use with 3mm salt only. Therefore, the 6.3mm salt used in the tests would have left the spinner with higher momentum than required. This was also the case during the road trial carried out on the A52 (Burtwell and Zohrabi, 2004d).

The under-salting may have been the result of the high moisture content of the salt and its consolidation during the journey from Lincolnshire to TRL. A road trial involving the same spreader on a 2-lane carriageway showed much better performance (Burtwell and Zohrabi, 2004a).

2.4.4 Epoke Combi Sirius S4502 (brine spreading)

The brine discharged was, on average, 135, 91, 100 and 82 per cent, respectively, of the target levels at the four spread rates (12.1, 23, 32.7 and 42.4 g/m^2). Whereas there was little difference in the brine discharged in the two test runs when the target spread rate was $12.1g/m^2$, the brine discharged at the other three spread rates was about ±10 per cent of the mean of the spread rate.

2.4.5 Modified Schmidt Stratos B90 (dry salting with 6.3mm salt)

During tests with the hopper one-third full, the amount of salt discharged was 145 and 129 per cent, respectively, of the target level during asymmetric and symmetric spreading at $10g/m^2$. At the target spread rate of $20g/m^2$, the percentages were 100 and 111 per cent, respectively.

2.4.6 Modified Schmidt Stratos B90 (pre-wetted salting with 6.3mm salt)

During tests with the hopper one-third full, the amount of salt discharged was 101 and 161 per cent, respectively, of the target level during asymmetric and symmetric spreading at $10g/m^2$. At the target spread rate of $20g/m^2$, the percentages were 82 and 87 per cent.

2.4.7 Giletta 80501D (dry salting with 6.3mm salt)

The salt that came in the hopper from the north of Scotland was emptied and reloaded at a depot approximately 4 miles from TRL so the salt was not consolidated in the hopper.

During asymmetric spreading, the amount of salt discharged was, on average 145 and 160 per cent of the target level when the target spread rate was 10 and $20g/m^2$, respectively. At the lower spread rate, about 50 per cent more salt was discharged when the hopper was 10 per cent full than when it was full. At the higher spread rate, the amount of salt discharged was similar for both hopper loads.

The salt grading lay towards the coarser end of the BS3247 limit, and the salt had a high moisture content, 6.4 per cent.

2.5 Achieved spread rates and wastage to the roadside verges and margins

The transverse salt distribution profiles obtained from each of the three strips in the eight test runs of each test are shown in Figures A.1 to A.6. They show the uniformity of the salt distribution across the target area and along the salting path. The position of each lane of the target area is shown. In the tests when the nearside hard shoulder was not part of the target area, the verges and margins are identified as hard shoulders in the figures. In the tests when the nearside hard shoulder was part of the target area, the nearside verge and margin are identified as the verge, and the offside verge and margin are identified as the central reserve (CR).

In this section, the amount of salt delivered to and outside the target area is discussed separately for asymmetric and symmetric spreading for each spreader. The next section considers the variations in the salt distribution profiles from strip to strip which indicate whether there was any transverse and/or longitudinal snaking.

The effect of the wind speed and its direction and the moisture content of the salt on the salt distribution and wastage to outside the target area are discussed for some trials.

2.5.1 Asymmetric spreading

The percentage of the target spread rate achieved within each lane is given in Table 4. The wastage to the left-hand and right-hand verges and margins as a percentage of the total discharged salt is shown in Table 5.

The data for dry and pre-wetted salting are for two spread rates of 10 and 20g/m^2. The pre-wetted salt dosage is based on a 70:30 mixture of dry salt to a 23.5 per cent solution of brine, thus corresponding to 7.7 and 15.4g/m^2 of pure salt for 10 and 20g/m^2 of pre-wetted salt, respectively.

The brine density was 1.21g/cm^3 and the brine concentration was 23.5 per cent, so the spread rates of 10, 19, 27 and 35 ml/m^2 (Table 2) correspond to 2.8, 5.4, 7.7 and 10.0g/m^2, respectively, of pure salt.

2.5.1.1 Econ Zero C Mk 4 – 2002 model (dry salting with 6.3mm salt)

The amount of salt delivered to the target area was, on average, 79 and 43 per cent, respectively, of the target level when the spread rate was 10 and 20 g/m^2. Above 2.5 times as much salt was delivered to the target area when the hopper was 10 per cent full than when it was full.

The total wastage was, on average, 16 and 36 per cent of the salt discharged when the target spread rate was 10 and 20g/m^2. At the lower spread rate, the total wastage was similar for both hopper loads. The wastage was slightly higher to the offside verge than to the nearside verge in three test runs, but was about 2.5 times higher to the offside verge than the nearside verge when the hopper was full and the target spread rate was 20g/m^2.

The wind speed was low (1 to 3 mph) and its direction was north-easterly, i.e. tending from lane 1 to lane 2, so the overall effect on the salt delivery would have been negligible.

2.5.1.2 Econ Zero C Mk 4 – 2002 model (pre-wetted salting with 3mm salt)

The amount of salt delivered to the target area was, on average, 63 and 80 per cent, respectively, of the target level when the spread rate was 10 and 20g/m^2. At the lower target spread rate, much more salt was delivered to the target area when the hopper was full than when it was 10 per cent full. At the higher target spread rate, slightly more salt was delivered to the target area when the hopper was full than when it was 10 per cent full. Whereas, the amount of salt in lanes 1 and 2 was reasonably similar in each lane in three test runs, about three times as much salt was delivered to lane 2 than to lane 1 when the hopper was full and the target spread rate was 20g/m^2.

The total wastage was, on average, 10 and 11 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2. It was slightly higher when the hopper was full rather than 10 per cent full. The wastage was similar to the nearside and offside verges and margins in three test runs, but higher to the offside than the nearside when the hopper was full and the target spread rate was 20g/m^2.

The wind speed was high (5 to 11 mph) during pre-wetted salting with the hopper full, and was from the south east, i.e. tending from lane 1 to lane 2. The wind speed was low (1 to 2 mph) and easterly for the tests when the hopper was 10 per cent full. The coverage in lane 2 and the wastage to the offside verge and margin suggest that the wind may have had an effect in the tests with the hopper full.

Table 4. Percentage of target spread rate achieved in different lanes during asymmetric spreading

Trial No.	Spreader type	Type of salting	Percentage of target spread rate (%)								
			Hopper full				Hopper 10 per cent full				Avg. of all spread lanes
			HS	Lane 1	Lane 2	Lane 3	HS	Lane 1	Lane 2	Lane 3	
1	Econ Zero C Ml 4 – 2002 model	Dry (10g/m^2)		30	53			111	123		79
		Dry (20g/m^2)		22	29			60	59		43
2		Pre-wetted (10g/m^2)		72	85			54	41		63
		Pre-wetted (20g/m^2)		39	125			72	82		80
3	Epoke Sirius SH3500	Pre-wetted (10g/m^2)		39^{ζ}	37^{ζ}			70^{ζ}	45^{ζ}		48^{ζ}
		Pre-wetted (20g/m^2)		30^{ζ}	31^{ζ}			62^{ζ}	37^{ζ}		40^{ζ}
4	Epoke Combi Sirius S4502*	Brine (12.1g/m^2)		125	97						
		Brine (23.0g/m^2)		75	65						
		Brine (32.7g/m^2)		107	60						
		Brine (42.4g/m^2)		53	67						
5	Modified** Schmidt	Dry (10g/m^2)	147	181	161	49					132
		Dry (20g/m^2)	150	127	78	30					87
6		Pre-wetted (10g/m^2)	110	167	87	22					94
		Pre-wetted (20g/m^2)	106	111	73	22					73
7	Giletta 80501D	Dry (10g/m^2)		35	90			51	111		72
		Dry (20g/m^2)		44	131			37	101		79

Note: Shaded cells were outside target area
* Brine discharged under constant pressure, so independent of amount of brine in the hopper
** Trials carried out with hopper one-third full
ζ Wrong spinner speed used and/or possible salt consolidation in the hopper

Table 5. Quantity of salt delivered outside target area during asymmetric spreading

Trial No.	Spreader type	Type of salting	Amount of salt delivered outside target area (% by weight of total discharged)			
			Hopper full		Hopper 10 per cent full	
			Nearside (left)verge and margin	Offside (right) verge and margin	Nearside (left) verge and margin	Offside (right) verge and margin
1	Econ Zero C Mk 4 – 2002 model	Dry (10g/m^2)	5	7	9	10
		Dry (20g/m^2)	11	26	16	19
2		Pre-wetted (10g/m^2)	6	5	5	4
		Pre-wetted (20g/m^2)	3	11	4	3
3	Epoke Sirius SH3500	Pre-wetted (10g/m^2)	16	6	18	9
		Pre-wetted (20g/m^2)	13	14	14	12
4	Epoke Combi Sirius S4502*	Brine (12.1g/m^2)	8	10		
		Brine (23.0g/m^2)	8	14		
		Brine (32.7g/m^2)	7	9		
		Brine (42.4g/m^2)	8	18		
5	Modified** Schmidt Stratos B90-42-VALN5Z	Dry (10g/m^2)	6	3		
		Dry (20g/m^2)	11	2		
6		Pre-wetted (10g/m^2)	6	1		
		Pre-wetted (20g/m^2)	9	2		
7	Giletta 80501D	Dry (10g/m^2)	7	39	6	47
		Dry (20g/m^2)	3	41	3	55

* Brine discharge is under a constant pressure and is independent of the brine quantity in the hopper
** Trials carried out the hopper one-third full

2.5.1.3 Epoke Sirius SH3500 (pre-wetted salting with 6.3mm salt)

The test runs were carried out with the spinner speed set incorrectly. Also, the salt may have been consolidated in the hopper. The amount of salt delivered to the target area was, on average, 48 and 40 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. Both lanes were under-salted by 61 per cent or more when the hopper was full. More salt was delivered to lane 1 than to lane 2 when the hopper was 10 per cent full, but the most salted lane received only 70 per of the target level.

The total wastage was, on average, 25 and 26 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2. At the lowest target spread rate, there was more wastage to the nearside than to the offside verge and margin. At the highest target spread rate, the wastage was similar on both sides of the target area.

2.5.1.4 Epoke Combi Sirius S4502 (brine spreading)

The amount of brine delivered to the target area ranged from, on average, 60 to 111 per cent of the target level at the four target spread rates. The brine delivered to lane 1 ranged from 53 to 125 per cent of the target, whereas that delivered to lane 2 ranged from 60 to 97 per cent of the target level. The highest percentage delivered to each lane was when the target spread rate was 12.1 g/m^2. More brine was delivered to lane 1 than lane 2.

The wastage ranged from 16 to 26 per cent of the brine discharged, with more to the nearside than the offside verge and margin.

The wind speed did not exceed 2 mph on both days.

2.5.1.5 Modified Schmidt Stratos B90 (dry salting with 6.3mm salt)

The amount of salt delivered to the target area when the hopper was one third full was, on average, 132 and 87 per cent, respectively, of the target level when the target spread rate was 10 and $20g/m^2$. At $10g/m^2$, the hard shoulder and lanes 1 and 2 were over-salted by 47 per cent or more, whereas the salt delivered to lane 3 was less than 50 per cent of the target level. At $20g/m^2$, the hard shoulder and lane 1 were over-salted by 50 and 27 per cent, respectively, but lanes 2 and 3 were under-salted by 22 and 70 per cent, respectively.

The total wastage was 9 and 13 per cent, respectively, of the salt discharged when the target spread rate was 10 and $20g/m^2$. Most of the wastage was to the nearside verge and margin, especially at the higher target spread rate.

2.5.1.6 Modified Schmidt Stratos B90 (pre-wetted salting with 6.3mm salt)

The amount of salt delivered to the target area when the hopper was one third full was, on average, 94 and 73 per cent, respectively, of the target level when the target spread rate was 10 and $20g/m^2$. At both spread rates, the hard shoulder was over-salted by no more than 10 per cent. Lane 1 was also over-salted, by as much 67 per cent at $10g/m^2$, but less so at the higher spread rate. Lane 2 was under-salted by, on average 20 per cent, and lane 3 was under-salted by 78 per cent at both spread rates.

The total wastage was 7 and 11 per cent, respectively, of the salt discharged when the target spread rate was 10 and $20g/m^2$. Most of the wastage was to the nearside verge and margin.

Although the wind direction was towards the offside verge, its speed was low (1 to 5 mph) during both dry and pre-wetted salting. Hence, the effect of the wind was not considered to be significant.

2.5.1.7 Giletta 80501D (dry salting with 6.3mm salt)

The amount of salt delivered to the target area was, on average, 72 and 79 per cent, respectively, of the target level when the target spread rate was 10 and $20g/m^2$. At $10g/m^2$, more salt was delivered to the target area when the hopper was 10 per cent full than when it was full. The opposite was found at the higher target spread rate. The salt delivered to lane 1 ranged from 35 to 51 per cent of the target level, whereas that delivered to lane 2 ranged from 90 to 131 per cent of the target level.

The total wastage was, on average, 50 and 51 per cent, respectively, of the salt discharged when the target spread rate was 10 and $20g/m^2$. The wastage was higher when the hopper was 10 per cent full than when it was full. Most of the wastage was to the offside verge and margin.

It appears that some salt was delivered beyond the end of the test strips.

The wind speed was low (1 to 3 mph) and tended from lane 1 to lane 2. As said previously, the moisture content of the salt was high and this may have been responsible for the high quantity of salt in lane 2 and wastage to the offside verge and margin.

2.5.2 Symmetric spreading

The percentage of the target spread rate achieved within each lane is given in Table 6. The wastage to the left-hand and right-hand verges and margins as a percentage of the total discharged salt is shown in Table 7.

2.5.2.1 Econ Zero C Mk 4 – 2002 model (dry salting with 6.3mm salt)

The amount of salt delivered to the target area was, on average, 66 and 54 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. More salt was delivered to the target area when the hopper was 10 per cent full than when it was full. Much more salt was delivered to lane 1 than to lane 2. With the hopper 10 per cent full, lane 2 was only slightly under-salted at both spread rates. However, in all four test runs, one lane was under-salted by a least 35 per cent.

The total wastage was, on average, 37 and 40 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2. There was more wastage to nearside than to the offside verge and margin.

Salt was wasted rather being delivered to the target area. This has environmental and safety implications.

The wind speed was low (1 to 3 mph) and was not considered to be a significant factor in the salt distribution.

2.5.2.2 Econ Zero C Mk 4 – 2002 model (pre-wetted salting with 3mm salt)

The amount of salt delivered to the target area was, on average, 92 and 66 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. At the lower spread rate, lane 1 was over-salted. There was a more even distribution of salt in the target area when the hopper was full than when it was 10 per cent full. In three test runs, the salt delivered to lane 2 was no more than 56 per cent of the target level.

The total wastage was, on average, 37 and 48 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2. When the hopper was full, there was about 2 to 3 times as much wastage to the nearside as to the offside verge and margin. When the hopper was 10 per cent full, almost all the wastage was to the nearside verge and margin.

As said previously, the wind speed was high (5 to 11 mph) during pre-wetted salting with the hopper full, and from lane 1 to lane 2. The lower wastage to the nearside verge and margin, and the higher coverage in lane 2 and the high wastage to the offside verge and margin suggest that the wind had an effect on the salt distribution in the tests with the hopper full.

2.5.2.3 Epoke Sirius SH3500 (pre-wetted salting with 6.3mm salt)

The amount of salt delivered to the target area was, on average, 101 and 62 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. More salt was delivered to the target area when the hopper was 10 per cent full than when it was full. When the hopper was full, more salt was delivered to lane 2 than to lane 1. The opposite was the case when the hopper was 10 per cent full.

Table 6. Percentage of target spread rate achieved in different lanes during symmetric spreading

Trial No.	Spreader type	Type of salting	Percentage of target spread rate (%)								
			Hopper full				Hopper 10 per cent full				Avg. of all spread lanes
			HS	Lane 1	Lane 2	Lane 3	HS	Lane 1	Lane 2	Lane 3	
1	Econ Zero C Mk 4 – 2002 model	Dry (10g/m^2)		69	34			97	65		66
		Dry (20g/m^2)		54	25			94	45		54
2		Pre-wetted (10g/m^2)		122	89			104	51		92
		Pre-wetted (20g/m^2)		74	56			89	43		66
3	Epoke Sirius SH3500	Pre-wetted (10g/m^2)		78	107			127	93		101
		Pre-wetted (20g/m^2)		20	84			85	61		62
4	Epoke Combi Sirius S4502*	Brine	Symmetric spreading was not possible with the tested spreader model								
5	Modified** Schmidt Stratos B90-42-VALN5Z	Dry (10g/m^2)	17	113	238	68					124**
		Dry (20g/m^2)	14	119	152	87					106**
6		Pre-wetted (10g/m^2)	56	189	240	68					152**
		Pre-wetted (20g/m^2)	14	109	114	58					84**
7	Giletta 80501D	Dry	Symmetric spreading was not carried out as it is not practised in Scotland								

Note: Shaded cells were outside target area ** Trials carried out with a one-third full hopper load

Table 7. Quantity of salt delivered outside target area during symmetric spreading

Trial No.	Spreader type	Type of salting	Amount of salt delivered outside target area (% by weight of total discharged)			
			Hopper full		Hopper 10 per cent full	
			Nearside (left)verge and margin	Offside (right) verge and margin	Nearside (left) verge and margin	Offside (right) verge and margin
1	Econ Zero C Mk 4 – 2002 model	Dry (10g/m^2)	19	15	23	17
		Dry (20g/m^2)	29	16	23	12
2		Pre-wetted (10g/m^2)	23	11	35	4
		Pre-wetted (20g/m^2)	38	12	42	4
3	Epoke Sirius SH3500	Pre-wetted (10g/m^2)	16	5	19	4
		Pre-wetted (20g/m^2)	5	24	10	14
4	Epoke Combi Sirius S4502*	Brine	Symmetric spreading was not possible with the tested spreader model			
5	Modified** Schmidt Stratos B90-42-VALN5Z	Dry (10g/m^2)	2	2		
		Dry (2g/m^2)	1	4		
6		Pre-wetted (10g/m^2)	4	2		
		Pre-wetted (20g/m^2)	2	3		
7	Giletta 80501D	Dry	Symmetric spreading was not carried out as it is not practised in Scotland			

* Brine discharge is under a constant pressure and is independent of the brine quantity in the hopper
** Trials carried out with a one-third full hopper load

The total wastage was, on average, 22 and 27 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2. Most of the wastage was to the nearside verge and margin when the target spread rate was 10g/m^2. The opposite was the case at the higher spread rate.

2.5.2.4 Modified Schmidt Stratos B90 (dry salting with 6.3mm salt)

In tests with the hopper one third full, the amount of salt delivered to the target area was 124 and 106 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. Lanes 1 and 2 were over-salted by from 13 to 138 per cent, with most over-salting in lane 2. More salt was delivered to lane 3 at the higher spread rate than at the lower rate, being 87 and 68 per cent, respectively, of the target. Very little salt was delivered to the hard shoulder - no more than 17 per cent of the target level.

The total wastage was, on average, 4 and 5 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2.

2.5.2.5 Modified Schmidt Stratos B90 (pre-wetted salting with 6.3mm salt)

In tests with the hopper one third full, the amount of salt delivered to the target area was 152 and 84 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. Lanes 1 and 2 were over-salted by from 9 to 140 per cent, with most over-salting at the lower spread rate. The amount of salt was delivered to lane 3 and the hard shoulder was not more than 68 and 56 per cent, respectively, of the target level. Little salt was delivered to the hard shoulder at the higher spread rate.

The total wastage was, on average, 6 and 4 per cent, respectively, of the salt discharged when the target spread rate was 10 and 20g/m^2.

2.6 Transverse and longitudinal snaking

Figures A.1 to A.6 show how the salt was distributed across the three test strips in each run of each test. Differences in the magnitude of the peaks in the salt distribution profiles from the three strips are indicative of longitudinal snaking. Differences in the positions of the peaks across the strips are indicative of transverse snaking.

Econ Zero C Mk 4: Dry salting: As there was considerable under-salting when the hopper was full, it is difficult to assess the level of snaking. When the hopper was 10 per cent full, there was longitudinal snaking during asymmetric spreading, but no significant snaking during symmetric spreading.

Econ Zero C Mk 4: Pre-wetted salting: There was longitudinal snaking during three of the four asymmetric spreading test runs. During symmetric spreading, there was some longitudinal and transverse snaking when the target spread rate was 10g/m^2, but more snaking at the higher spread rate when the hopper was 10 per cent full.

Epoke Sirius SH3500: Pre-wetted salting: During asymmetric spreading, there was some transverse snaking when the hopper was full, but less snaking when it was 10 per cent full. During symmetric spreading, there was no significant snaking when the hopper was full and the target spread rate was 10g/m^2, but there was transverse and longitudinal snaking during the other three test runs.

Epoke Sirius S4502: Brine spreading: There was longitudinal and transverse snaking in all test runs. It tended to be less at the lowest target spread rate.

Modified Schmidt Stratos B90-42-VALN5Z: Dry salting: There was little significant snaking during symmetric spreading when the target spread rate was 10g/m^2. There was longitudinal and transverse snaking in the other three test runs.

Modified Schmidt Stratos B90-42-VALN5Z: Pre-wetted salting: There was longitudinal snaking during symmetric spreading when the target spread rate was $10g/m^2$. There some snaking in the other three test runs.

Giletta 80501D: Dry salting: The symmetric spreading test runs were not carried out, but the asymmetric spreading test runs were repeated. The salt distribution profiles were different for test runs with the same target spread rate and hopper load. Although there was little snaking in some of the test runs, the repeats showed snaking, so it is concluded that there was significant snaking at all of the test conditions.

2.7 Effect of grain size on the salt distribution profile

The method described as in Interim Report 1 was used to determine the effect of grain size on the salt distribution profiles. Samples collected from each of the panels were compared with samples of virgin salt taken from the hoppers. All the samples were oven dried before they were graded. The results are shown in appendix Figure A.7. The spreading was asymmetric in all cases, which is the preferred spreading mode. It was carried out at the end of day two when the hopper was 10 per cent full (except for tests with the modified Schmidt spreader that were carried out with the hopper one third full). This meant that any factors relating to possible salt consolidation were minimised and were not considered to affect adversely the salt distribution.

Econ Zero C Mk 4 – 2002 model and 6.3mm rock salt: There was a higher percentage of large grains in lane 2 and the right verge and margin than in lane 1 and the left verge and margin.

Econ Zero C Mk 4 – 2002 model and 3mm rock salt: There was a higher percentage of large grains in lane 2 than in lane 1 and the left verge and margin. The quantity of salt deposited in the right margin and verge was not enough to carry out a grading. These findings are consistent with the results obtained for the 6.3mm salt with the same spreader. The moisture content of the salt discharged by the Econ spreader was in the range 1.6 to 1.8 per cent.

Epoke Sirius SH35000 and 6.3mm rock salt: There was little variation in the grading of the salt across the test panels. The moisture content of the salt was 5.4 per cent.

Modified Schmidt Stratos B90 and 6.3mm rock salt: The 3-lane asymmetric spreading produced a high percentage of large grains in lane 3 and a lower percentage of the finest grains in lane 2. The salt delivered to lane 1 and the hard shoulder was finer than the virgin salt. The wind direction was towards the offside verge, but the speed was low (1 to 5 mph). The moisture content of the salt was 1.9 per cent.

Giletta 80501D and 6.3mm Bröste salt: The virgin salt used in this trial was towards the coarser end of the grading envelope given by BS3247 (1991). In addition, the moisture content of the salt was higher than normal (6.4 per cent). The salt distributed to the offside verge and margin had a high percentage of large grains. The salt in the lanes 1 and 2 and the nearside verge and margin was finer than the virgin salt.

As found in Stage 1, there was a higher percentage of large grains further from the spreader than was present nearer to it.

2.8 Effect of moisture content

BS 3247 (BSI, 1991) indicates that the moisture content of the salt on delivery should not exceed four per cent. It also mentions that "*low moisture content salt may be provided following discussion between supplier and purchaser*". The suppliers of the different salts also claim that the moisture content of the salt is important in order to ensure consistent coverage.

Table 1 shows that the moisture contents of the salts ranged from 1.6 to 6.4 per cent. The moisture content of two salts exceeded the maximum limit specified in BS 3247 (BSI, 1991). However, this provided the opportunity to study the effect of high moisture content on the salt distribution.

2.8.1 Summary of grading and moisture content effects on the salt distribution

1. As all grades of specified salts within BS 3247 (BSI, 1991) contain a reasonable quantity of fines, the moisture requirement may need to be adhered to very closely and the decision to acquire a drier salt may require further consideration. It appears that for moisture contents below two per cent, there was a tendency for salts within lane 2 and the offside verges (or lane 3 during 3-lane spreading) to be coarser than the virgin salts, leaving more fines to be concentrated in lane 1 and the nearside verge and hard shoulder.

2. The Giletta spreader was able to throw the Bröste salt, which contained a much higher than specified moisture content, beyond the lane 2 boundary, regardless of the specified spread width of 6m. This salt contained less fines in comparison to other salts used in this study.

3. Capabilities of different spreaders in meeting the full width coverage and the possibility of their use for wider spread widths (i.e. wider than 2 lanes) may be enhanced by increasing the moisture content of the salt to a level above 4 per cent specified by BS 3247 (1991). Such spreaders, however, require calibration for the wetter products. The uniformity of such high moisture contents would have to be maintained throughout the storage life of the salts without an adverse impact on their anti-caking properties during spreading.

4. There was no significant differences between the spreaders used in distributing one de-icer rather than another de-icer for a given moisture condition. Regardless of the type of spreader used, it is crucial that each spreader is properly CALIBRATED for the intended product, with the fines content (i.e. less than 2-3mm grain size) and moisture content taken into account.

2.9 Other factors

1. The results discussed in this report are specific to the test conditions and weather conditions during the trials. During the pre-wetted salting tests on the Econ spreader, the wind speed was high when the hopper was full and low when the hopper was 10 per cent full. Some differences in the salt distributions in these tests can be attributed to the wind.

2. This is noticeable in the grading curves discussed in Section 2.7, where some finer grain sizes showed erratic behaviour in the vicinity of lane 1 and the nearside hard shoulder and verge. Although wind speed was not significant in most of the trials and had little impact on salt coverage to the outer lanes, it may have had some effect on the salt distribution profile of the finer grains in the area behind the spreader.

3 CONCLUSIONS

The results discussed in this report are for specific test conditions and climate at the test site during the trial periods. The variables include wind speed and direction, relative humidity, air and road surface temperature, salt moisture content, symmetry of application, quantity of salt within the hopper, type of salting operation (i.e. dry versus pre-wetted or brine only application) and the grading of salt.

Hence, the findings in the report are for the specific combinations of the above mentioned parameters. In order to make any generalisation on the overall performance of any spreading equipment under all test conditions, a further comprehensive study is needed which takes account of all the possible variables.

The main conclusions that can be drawn from the trials are:

3.1 Econ Zero C Mk 4 – 2002 model (dry salting with 6.3mm salt)

1. During 2-lane asymmetric spreading, the amount of salt discharged ranged from 41 and 145 per cent of the target level. The amount discharged when the hopper was 10 per cent full was more than twice that when the hopper was full, possibly because the salt was consolidated in the hopper. The salt delivered to lane 1 ranged from 22 to 111 per cent of the target level, whereas that delivered to lane 2 ranged from 29 to 123 per cent of the target level. On average, about twice as much salt was delivered to the target area at the lower target spread rate than at the higher spread rate. The wastage ranged from 12 to 37 per cent of the salt discharged, being higher at the higher target spread rate. There was more wastage to the offside than to the nearside verge and margin.

2. During 2-lane symmetric spreading, the amount of salt discharged ranged from 72 and 134 per cent of the target level, being higher when the hopper was 10 per cent full than when it was full, possibly because of consolidation of the salt in the hopper. The salt delivered to lane 1 ranged from 54 to 97 per cent of the target level, whereas that delivered to lane 2 ranged from 25 to 65 per cent of the target level. Generally, about twice as much salt was delivered to lane 1 than to lane 2. The wastage ranged from 34 to 45 per cent of the salt discharged, with more to the nearside than to the offside verge and margin.

3.2 Econ Zero C Mk 4 – 2002 model (pre-wetted salting with 3mm salt)

1. During 2-lane asymmetric spreading, the amount of salt discharged ranged from 52 and 96 per cent of the target level. More salt was discharged when the hopper was full than when it was 10 per cent full. The salt delivered to lane 1 ranged from 39 to 72 per cent of the target level, whereas that delivered to lane 2 ranged from 41 to 125 per cent of the target level. The percentage delivered to the target area was higher at the higher target spread rate than at the lower rate. The wastage ranged from 7 to 14 per cent of the salt discharged.

2. During 2-lane symmetric spreading, the amount of salt discharged ranged from 124 and 161 per cent of the target level. More salt was discharged when the hopper was full than when it was 10 per cent full, and the percentage was higher at the lower target spread rate. The salt delivered to lane 1 ranged from 74 to 122 per cent of the target level, whereas that delivered to lane 2 ranged from 43 to 89 per cent of the target level. More salt was delivered to lane 1 than to lane 2 in all four test runs. The percentage delivered to the target area was higher at the lower target spread rate than at the higher rate. The wastage ranged from 34 to 50 per cent of the salt discharged, with more to the nearside than the offside verge and margin, and almost all to the nearside when the hopper was 10 per cent full.

3.3 Epoke Sirius SH3500 (pre-wetted salting with 6.3mm salt)

1. During 2-lane asymmetric spreading, the amount of salt discharged ranged from 42 and 79 per cent of the target level. Less salt was discharged when the hopper was full than when it was 10 per cent full. The salt delivered to lane 1 ranged from 30 to 70 per cent of the target level, whereas that delivered to lane 2 ranged from 31 to 45 per cent of the target level. The wastage ranged from 22 to 27 per cent of the salt discharged, with most to the nearside verge and margin at the lower target spread rate, and with equal amounts to both sides of the target area at the higher rate.

2. During 2-lane symmetric spreading, the amount of salt discharged ranged from 73 to 142 per cent of the target level. Less salt was discharged when the hopper was full than when it was 10 per cent full, and that discharged at the lower target spread rate was above the target level. The salt delivered to lane 1 ranged from 20 to 127 per cent of the target level, whereas that delivered to lane 2 ranged from 61 to 107 per cent of the target level. More salt was delivered to lane 2 than to lane 1 when the hopper was full, but the opposite was the case when the hopper was 10 per cent full. At the lower target spread rate, the salt delivered to the target area was, on average, 1 per cent above the target level. The wastage

ranged from 21 to 29 per cent of the salt discharged, with more to the nearside than the offside verge and margin at the lower target spread rate, and the opposite at the higher rate.

3. Several factors could have affected the outcome of these tests. The spinner speed for 3mm salt was used for these tests, so the 6.3mm salt would have left the spinner with more momentum than is normal. The moisture content of the salt was 5.4 per cent. The salt may have been consolidated during the journey from Lincolnshire to TRL.

3.4 Epoke Combi Sirius S4502 (brine spreading)

1. During 2-lane asymmetric spreading, the salt discharged ranged from 74 to 136 per cent of the target level. There was little difference in the salt discharge in the two replicates when the target spread rate was 12.1g/m^2. At the other three target spread rates, the difference in the discharged in the two replicates ranged from 16 to 24 per cent of the target spread rate.

2. Averaged over the two replicates, the salt delivered to lane 1 ranged from 53 to 125 per cent of the target level, whereas the salt delivered to lane 2 ranged from 60 to 97 per cent of the target level. The percentages were highest in each lane at the lowest target spread rate. The wastage ranged from 16 to 26 per cent of the salt discharged, with more to the offside than the nearside verge and margin.

3. As the brine was discharged at constant pressure and the wind speed was low, the salt distribution would have been dependent mainly on the orientation of the nozzles of the spreading mechanism.

3.5 Modified Schmidt Stratos B90 (dry salting with 6.3mm salt)

1. During 3-lane asymmetric spreading with the hopper one third full, the salt discharged was 145 and 100 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. The salt delivered to the hard shoulder and lane 1 ranged from 127 to 181 per cent of the target level. That delivered to lane 2 was 161 per cent of the target level at the lower spread rate, but about half that at the higher rate. The salt delivered to lane 3 ranged from 30 to 49 per cent of the target level. The wastage ranged from 9 to 13 per cent of the salt discharged, with more to the nearside than the offside verge and margin.

2. During 3-lane symmetric spreading with the hopper one third full, the salt discharged was 129 and 111 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. The salt delivered to lane 1 ranged from 113 to 119 per cent of the target level. That delivered to lane 2 was 238 and 152 per cent, respectively, of the target level at the lower and higher spread rates. The salt delivered to lane 3 ranged from 68 to 87 per cent of the target level, whereas that delivered to the hard shoulder ranged from 14 to 17 per cent of the target. The wastage was about 4 per cent of the salt discharged.

3. Reversing the direction of the spinner disc did not produce a more uniform salt distribution.

3.6 Modified Schmidt Stratos B90 (pre-wetted salting with 6.3mm salt)

1. During 3-lane asymmetric spreading with the hopper one third full, the salt discharged was 101 and 82 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. The salt delivered to the hard shoulder and lane 1 ranged from 106 to 167 per cent of the target level. That delivered to lane 2 ranged from 73 to 87 per cent of the target level, whereas that delivered to lane 3 was 22 per cent of the target. The wastage ranged from 7 to 11 per cent of the salt discharged, with most to the nearside verge and margin.

2. During 3-lane symmetric spreading with the hopper one third full, the salt discharged was 161 and 87 per cent, respectively, of the target level when the target spread rate was 10 and 20g/m^2. The salt delivered to lanes 1 and 2 was, on average, 215 and 112 per cent, respectively, of the target level at the lower and higher spread rates. The salt delivered to lane 3 ranged from 58 to 68 per cent of the target level, whereas that delivered to the hard shoulder ranged from 14 to 56 per cent of the target level. The wastage was about 6 per cent of the salt discharged.

3. Reversing the direction of the spinner disk did not produce a more uniform salt distribution.

3.7 Giletta 80501D (dry salting with 6.3mm salt)

1. During 2-lane asymmetric spreading, the salt discharged ranged from 115 to 174 per cent of the target level. The salt delivered to lane 1 ranged from 35 to 51 per cent of the target level, and that delivered to lane 2 ranged 90 to 131 per cent of the target level. The wastage ranged from 44 to 58 per cent of the salt discharged, with most to the offside verge and margin.

3.8 Other factors

1. The moisture content of the salt had a significant effect on the salt distribution profile, particularly when higher than 4 per cent at the time of spreading. Excessive moisture content encourages larger salt grains to travel further and the fines to concentrate at the rear of the spreader.

2. During the pre-wetted salting tests on the Econ spreader, the wind speed was high when the hopper was full and low when the hopper was 10 per cent full. Some differences in the salt distributions in these tests can therefore be attributed to the wind.

3. Although wind speed was not significant in most of the trials and had little impact on salt coverage to the outer lanes, it may have had some effect on the salt distribution profile of the finer grains in the area behind the spreader. As found in Stage 1, there was a higher percentage of small grains near to the spreader than was present further from it.

4 NEXT STEPS

The suite of tests carried out on the TRL research track during the two Interim Stages relate to the dynamic performance of spreaders for a range of parameters such as salt quantity in the hopper, spread rate and symmetry of spread for a given salt grade and spreading technique. These trials have served to identify the different capabilities of each spreader tested. Some of these combinations were also tested in actual road trials that involved different degrees of trafficking (some with one-hour trafficking and others with full daytime trafficking).

The findings to date are reported in a Final Report on Phase 1 (Burtwell and Zohrabi, 2004b) which encompass the main conclusions from both Interim Reports. A best practice guidance document will also be prepared to provide practical guidance in spreading techniques for practicing engineers. It will also provide information about the current capabilities for each tested spreader/salt combination. Some guidance for the manufacturers and product suppliers concerning the future development of their spreading equipment/products to cater for a range of applications will be included.

As the spreaders and de-icing products are likely to be modified following the trials, it is envisaged that in Phase 2 of this research programme, it may be necessary to carry out further trials to re-assess the performance of the modified spreaders or the de-icing salts. Following this, the best practice document will be updated to include the lessons learned from the latest findings.

Five workshops are planned at different locations across the UK to review the outcome of the four-year research programme and to discuss a draft Business Plan for the next stage of the research.

5 ACKNOWLEDGEMENTS

The work described in this report was carried out in the Infrastructure Division of TRL Limited. The Project Manager and Technical Director is Mrs Marilyn Burtwell and the Quality Audit Review Officer is Mr Richard Jordan.

The author and project team wish to thank the members of the National Salt Spreading Research Steering Group as well as the Working Group for continuous support and encouragement throughout the trials. Also, the assistance of the many Highway Authorities, equipment and material suppliers and contractors who have contributed towards the performance trials is gratefully acknowledged.

Finally, the authors wish to thank Kevin Barker, Craig Thomas, Craig Roberts, Rob Beaumont, Bob Owen and Layla Baldachin of TRL for their valuable contribution to the performance trials.

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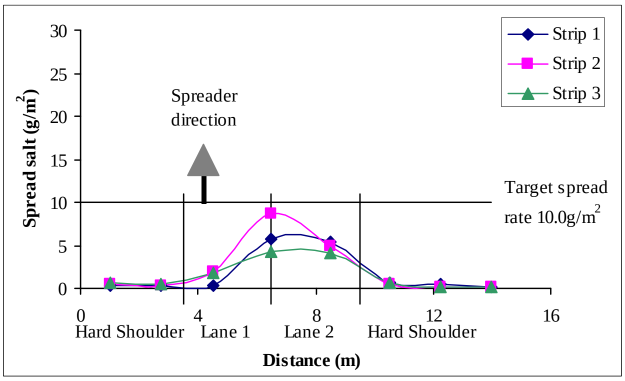
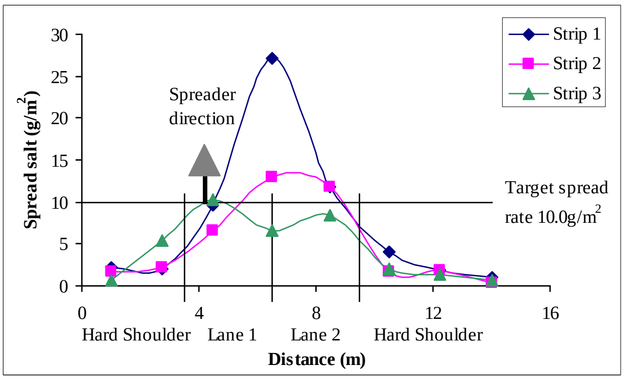
APPENDIX A. PERFORMANCE TRIALS DATA

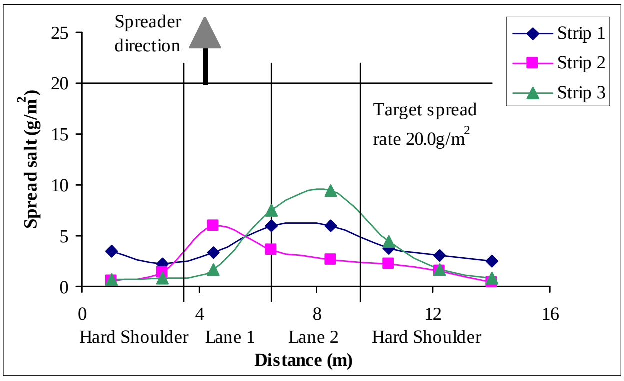
A.1 Salt distribution profiles for each run of each spreader test



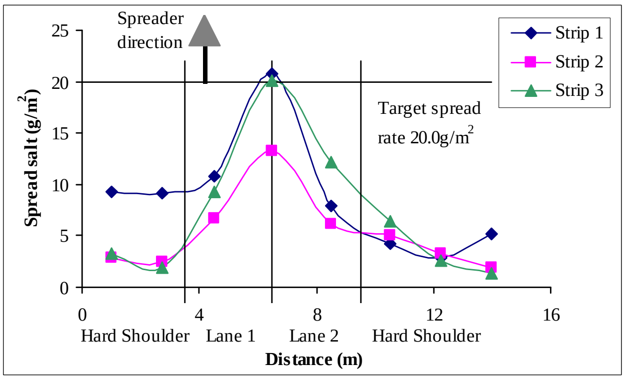
a) asymmetric spreading, 10g/m² - hopper full



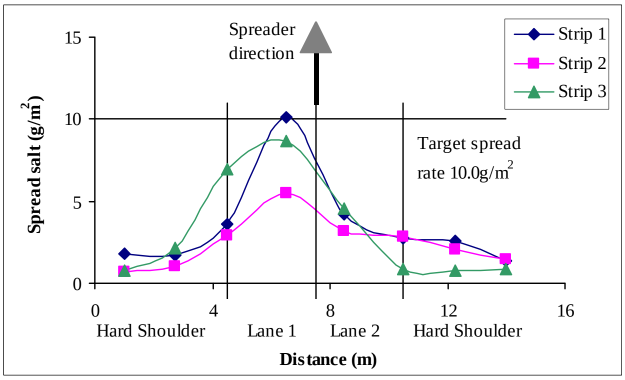
b) asymmetric spreading, 10g/m² - hopper 10% full



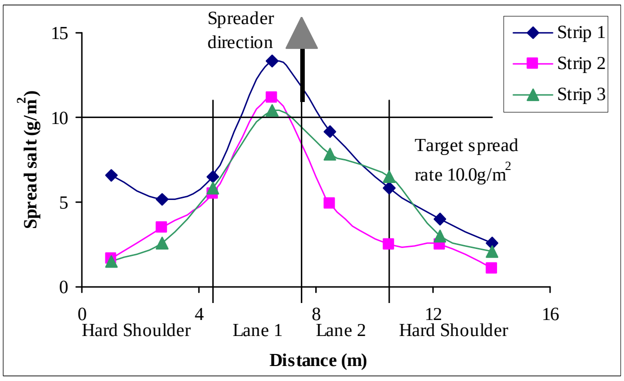
c) asymmetric spreading, 20g/m² – hopper full



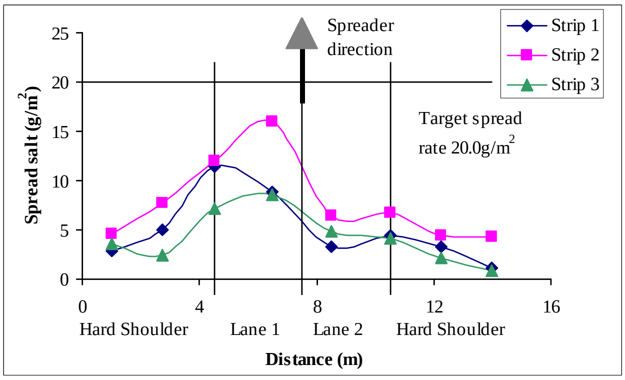
d) asymmetric spreading, 20g/m² - hopper 10% full



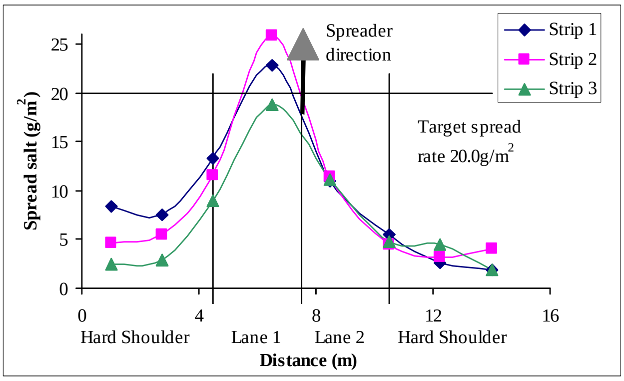
e) symmetric spreading, 10g/m² – hopper full



f) symmetric spreading, 10g/m² - hopper 10% full

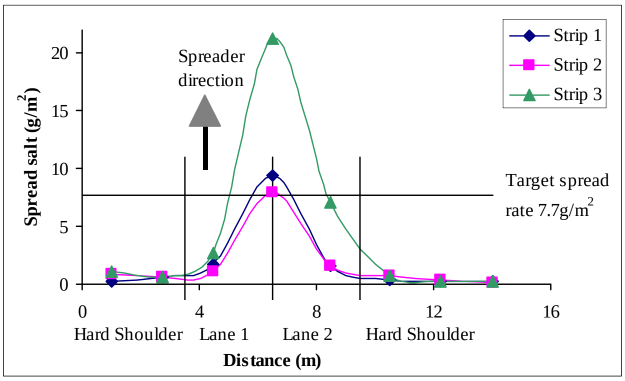


g) symmetric spreading, 20g/m² – hopper full

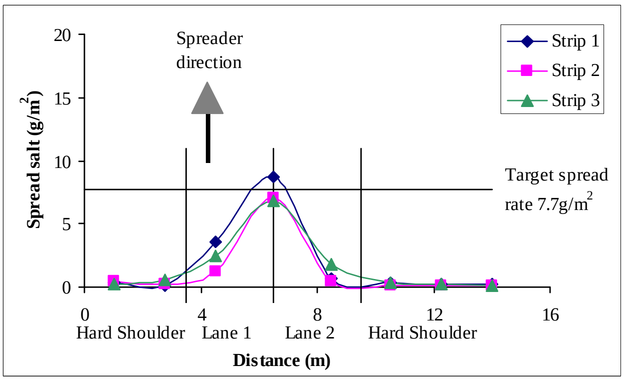


h) symmetric spreading, 20g/m² - hopper 10% full

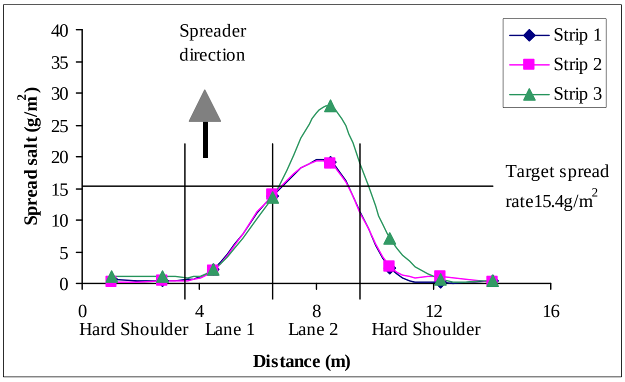
Figure A.1. Econ Zero C Mk 4 – 2002 model (dry salting with 6.3mm salt)



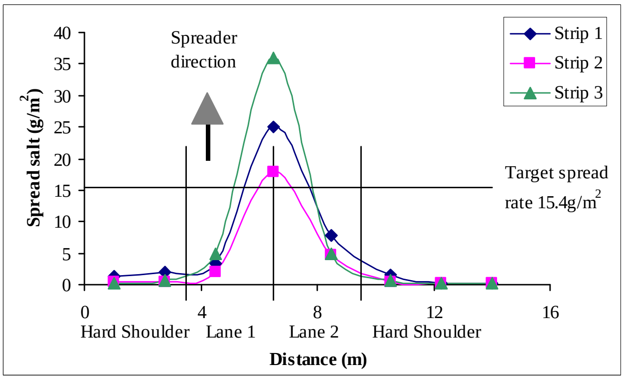
a) asymmetric spreading, 10g/m² - hopper full



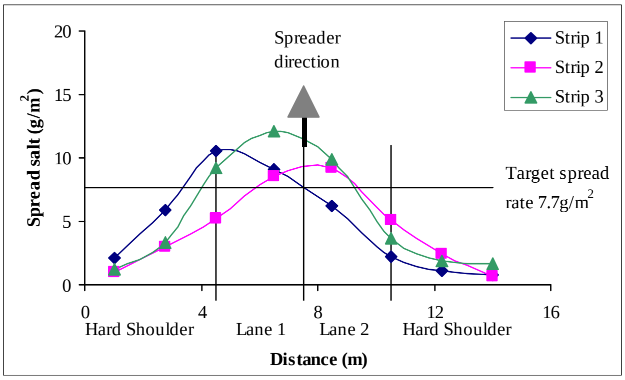
b) asymmetric spreading, 10g/m² - hopper 10% full



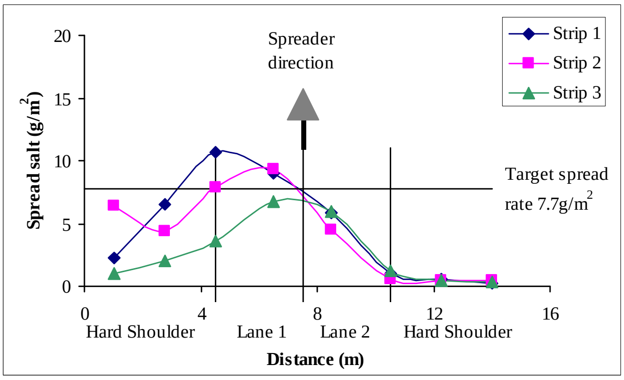
c) asymmetric spreading, 20g/m² – hopper full



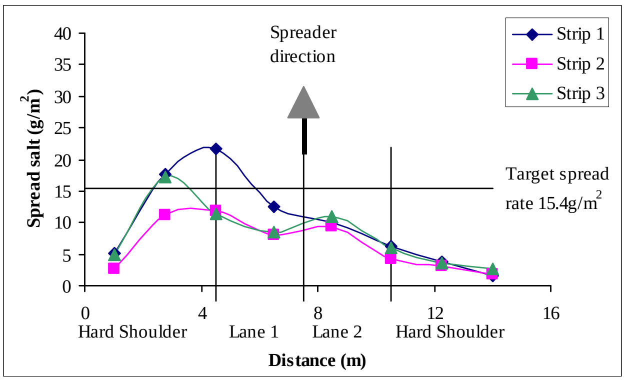
d) asymmetric spreading, 20g/m² - hopper 10% full



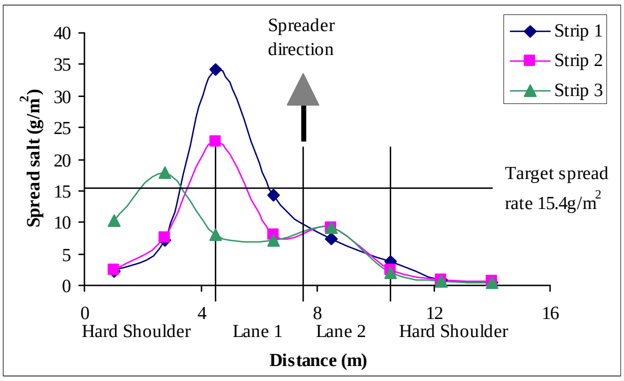
e) symmetric spreading, 10g/m² – hopper full



f) symmetric spreading, 10g/m² - hopper 10% full

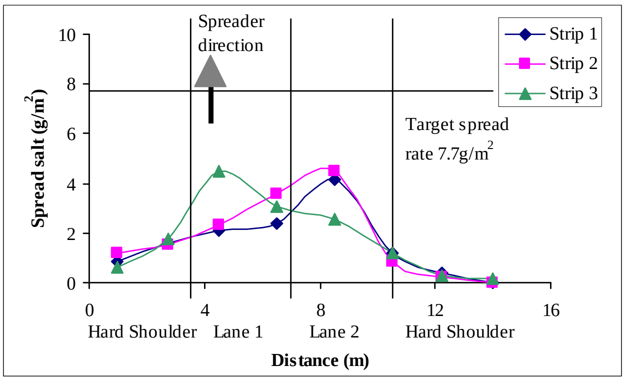


g) symmetric spreading, 20g/m² – hopper full

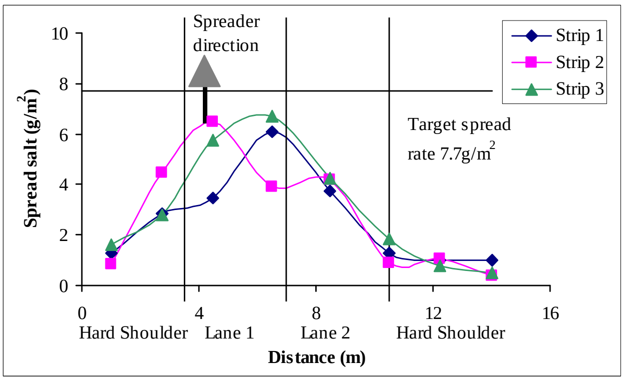


h) symmetric spreading, 20g/m² - hopper 10% full

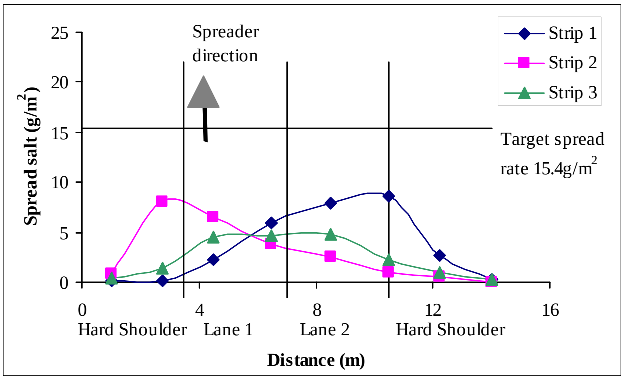
Figure A.2. Econ Zero C Mk 4 – 2002 model (pre-wetted salting with 3mm salt)



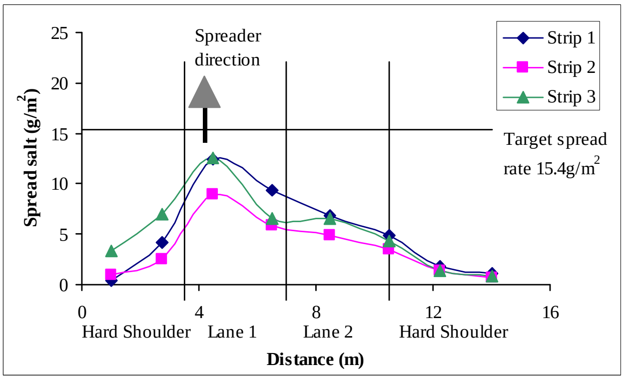
a) asymmetric spreading, 10g/m² - hopper full



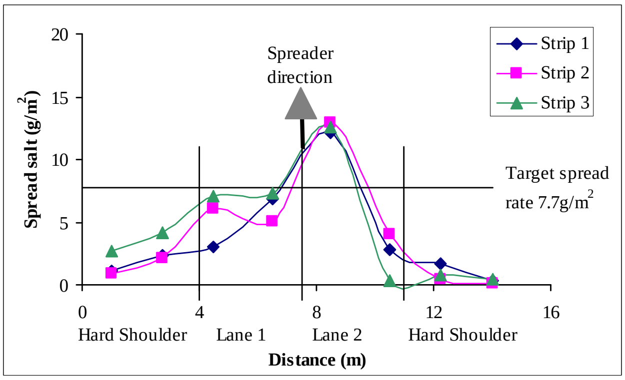
b) asymmetric spreading, 10g/m² - hopper 10% full



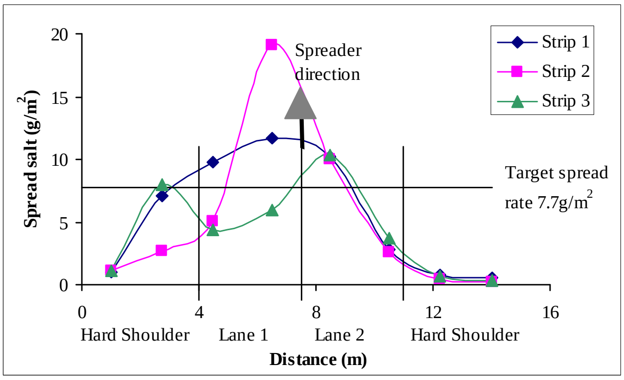
c) asymmetric spreading, 20g/m² – hopper full



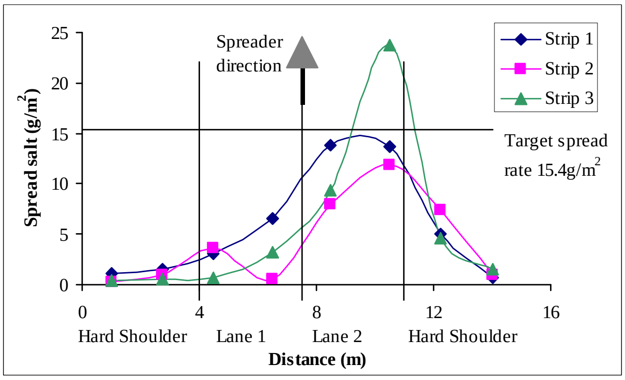
d) asymmetric spreading, 20g/m² - hopper 10% full



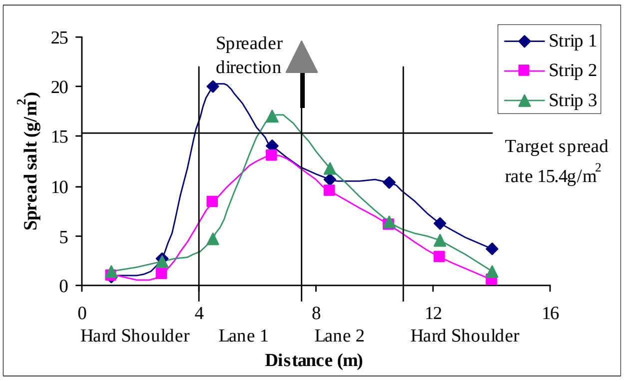
e) symmetric spreading, 10g/m² – hopper full



f) symmetric spreading, 10g/m² - hopper 10% full

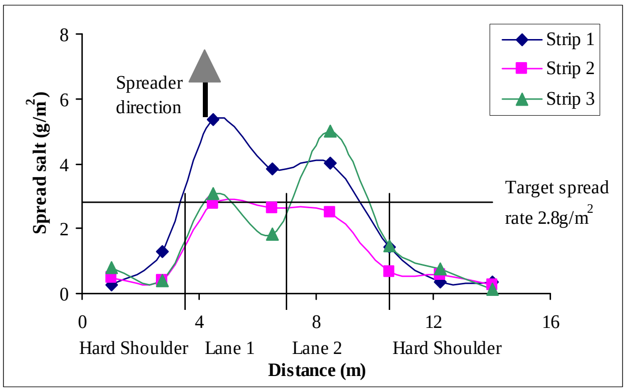


g) symmetric spreading, 20g/m² – hopper full

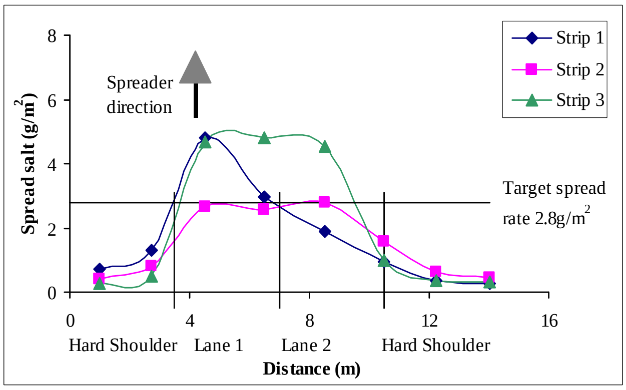


h) symmetric spreading, 20g/m² - hopper 10% full

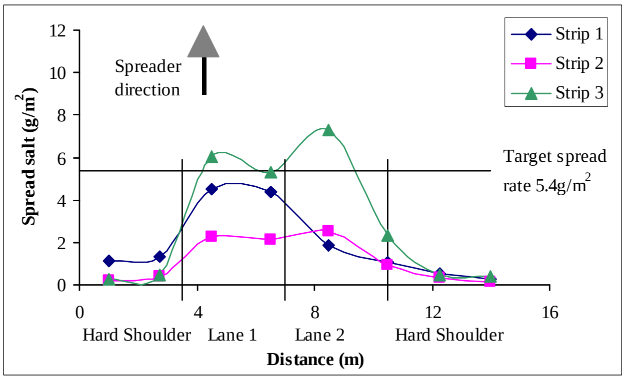
Figure A.3. Epoke Sirius SH3500 (pre-wetted salting with 6.3mm salt)



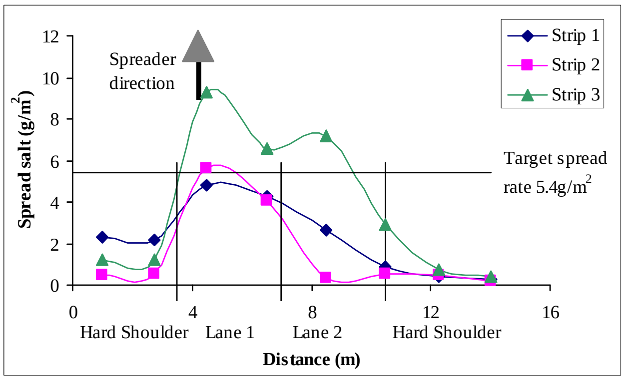
a) asymmetric spreading, 10ml/m²



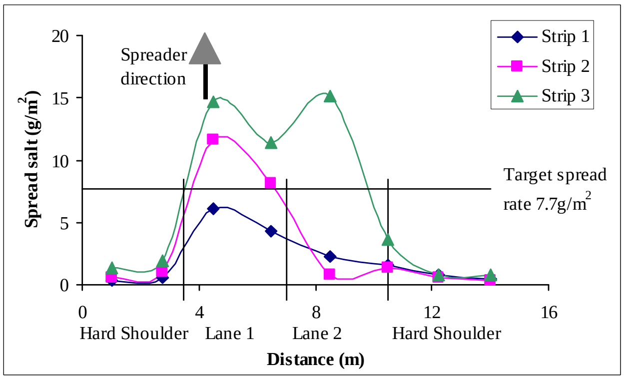
b) asymmetric spreading, 10ml/m² – repeat



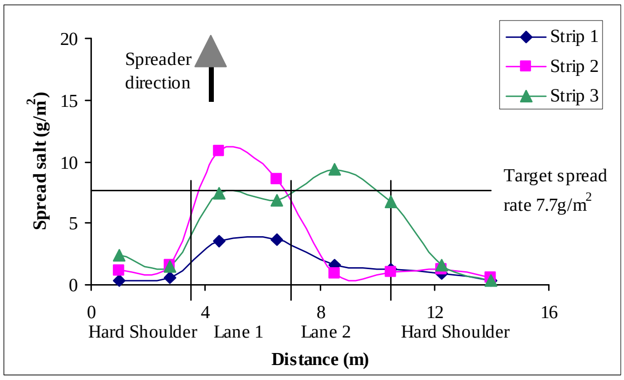
c) asymmetric spreading, 19ml/m²



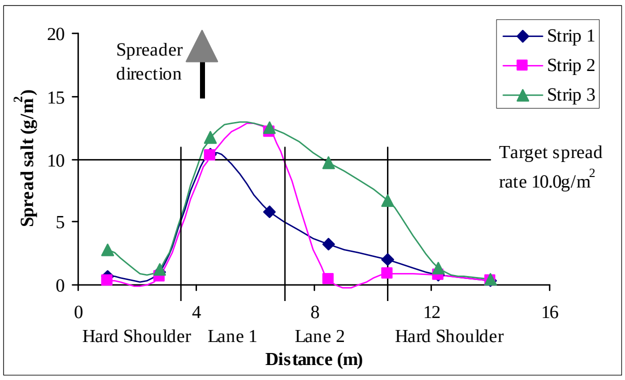
d) asymmetric spreading, 19ml/m² - repeat



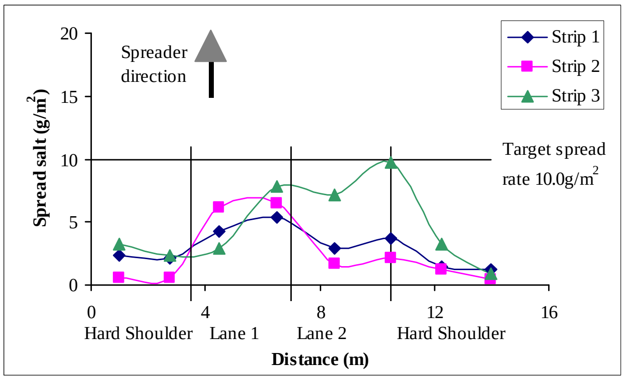
e) asymmetric spreading, 27ml/m²



f) asymmetric spreading, 27ml/m² – repeat

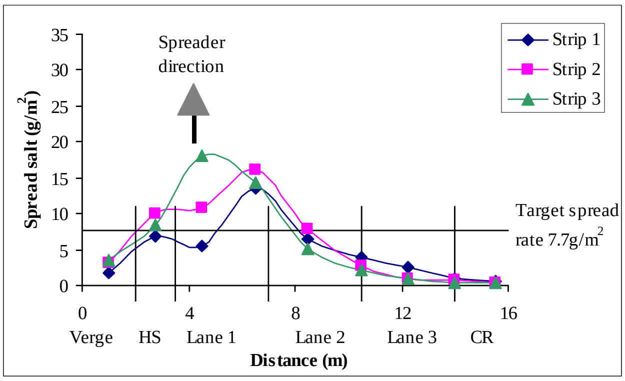


g) asymmetric spreading, 35ml/m²

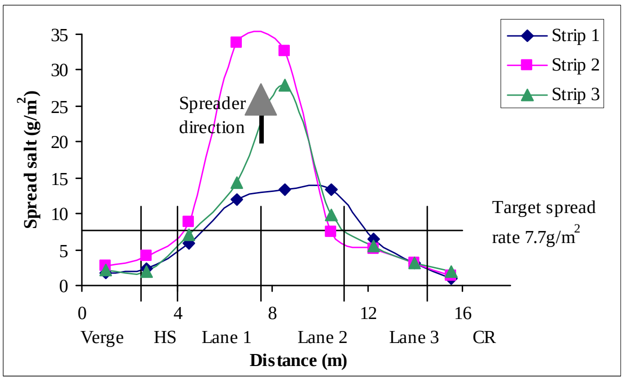


h) asymmetric spreading, 35ml/m² - repeat

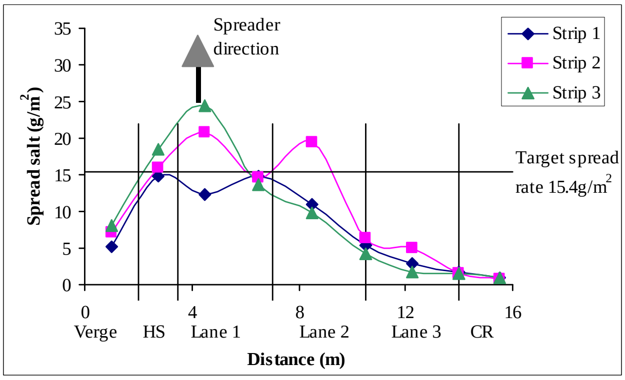
Figure A.4. Epoke Sirius S4502 (brine spreading)



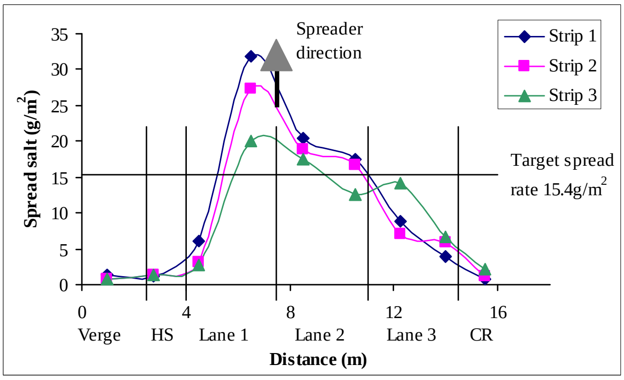
a) asymmetric spreading, 10g/m² - pre-wet



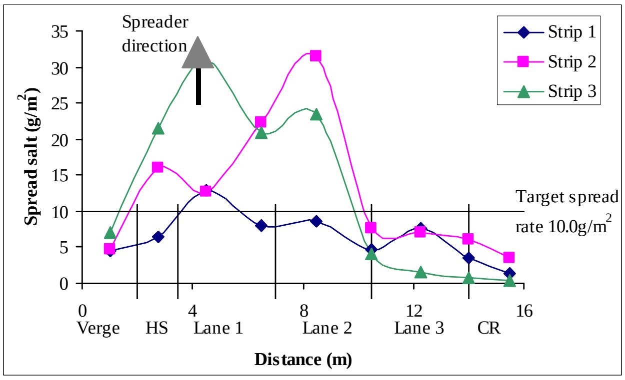
b) symmetric spreading, 10g/m² – pre-wet



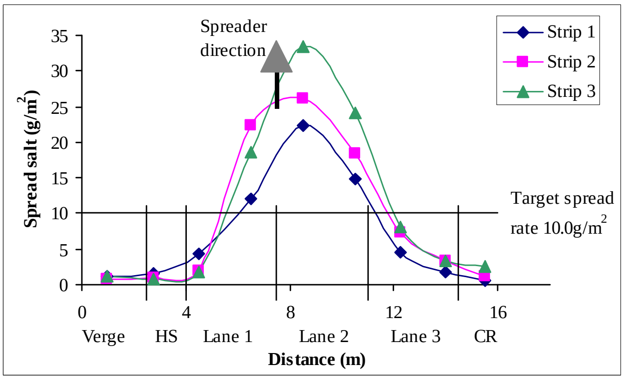
c) asymmetric spreading, 20g/m² - pre-wet



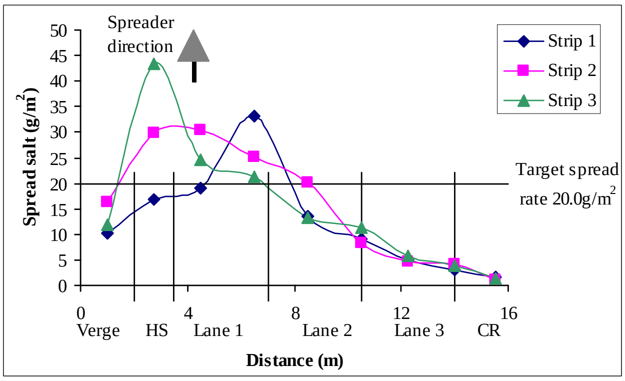
d) symmetric spreading, 20g/m² – pre-wet



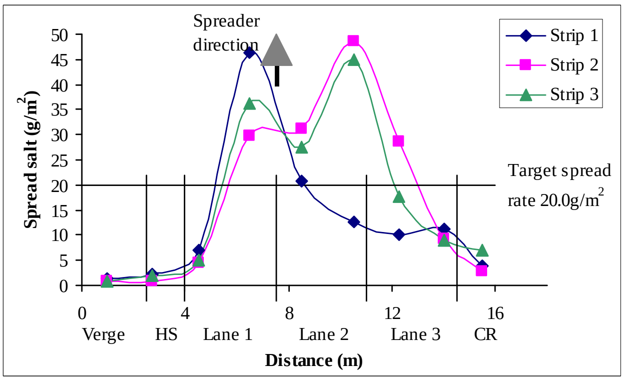
e) asymmetric spreading, 10g/m² - dry



f) symmetric spreading, 10g/m² - dry

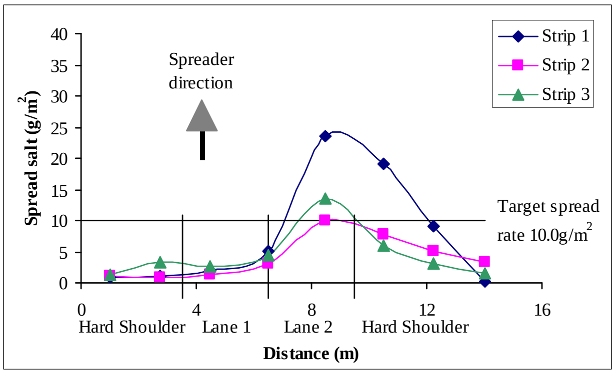


g) asymmetric spreading, 20g/m² - dry

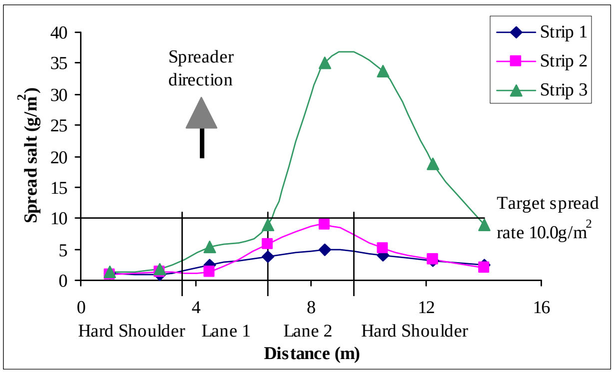


h) symmetric spreading, 20g/m² – dry

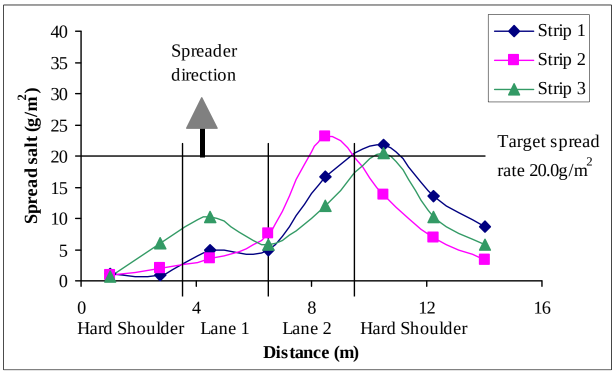
Figure A.5. Modified Schmidt Stratos B90-42-VALN5Z (dry and pre-wetted salting with 6.3mm salt)



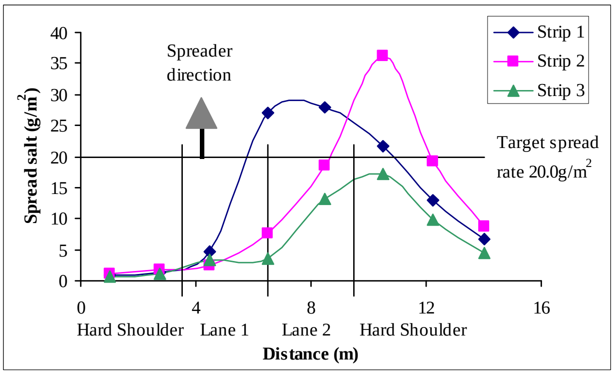
a) asymmetric No. 1, 10g/m^2 - hopper full



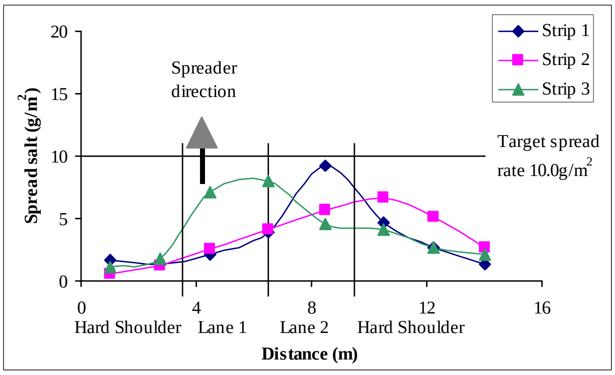
b) asymmetric No. 1, 10g/m^2 - hopper 10% full



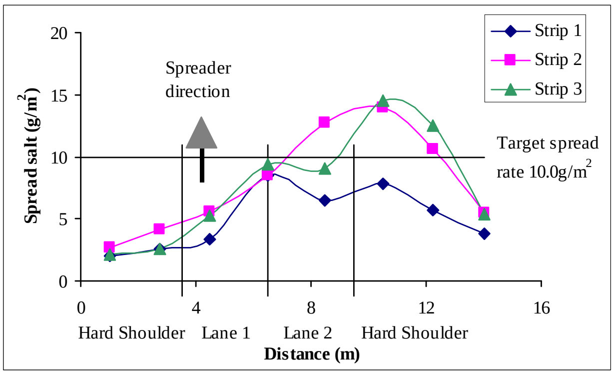
c) asymmetric No. 1, 20g/m^2 – hopper full



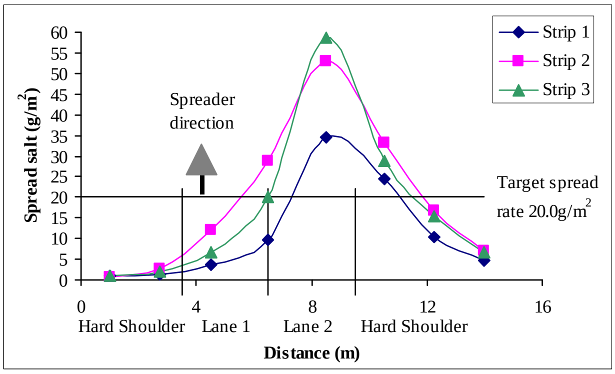
d) asymmetric No. 1, 20g/m^2 - hopper 10% full



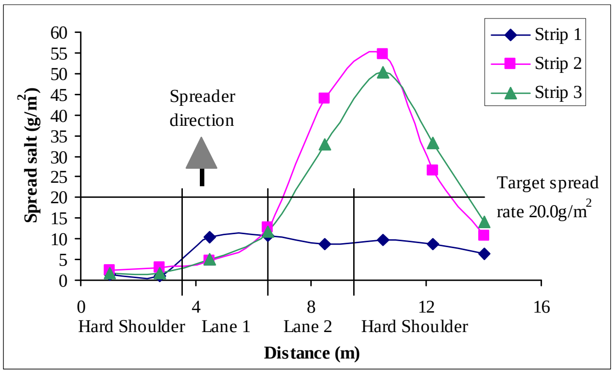
e) asymmetric No. 2, 10g/m^2 – hopper full



f) asymmetric No. 2, 10g/m^2 - hopper 10% full



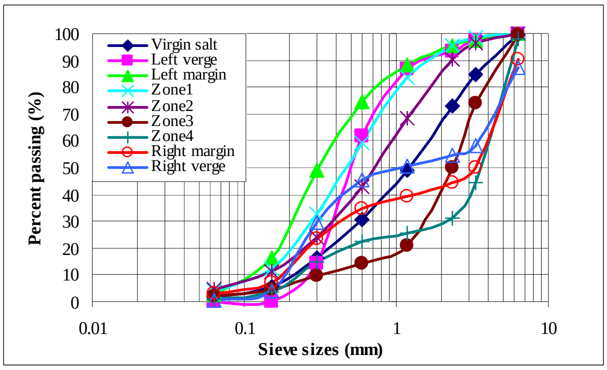
g) asymmetric No. 2, 20g/m^2 – hopper full



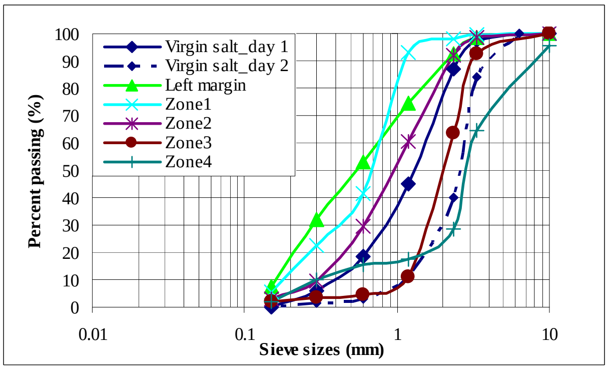
h) asymmetric No. 2, 20g/m^2 - hopper 10% full

Figure A.6. Giletta 80501D (dry salting with 6.3mm salt)

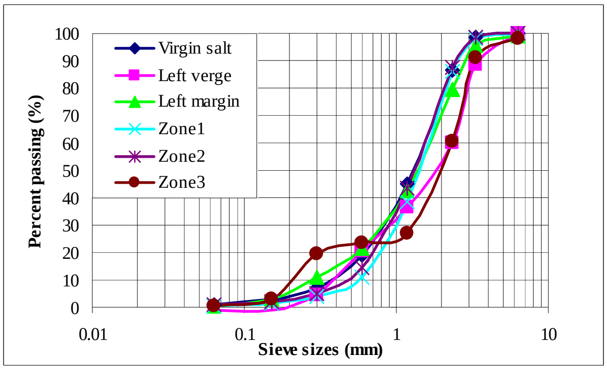
A.2 Salt particle size distributions



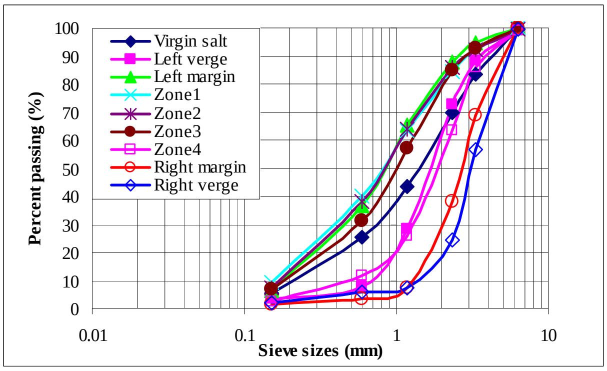
(a) Econ Zero C Mk 4 - 2002 model, 6.3mm salt



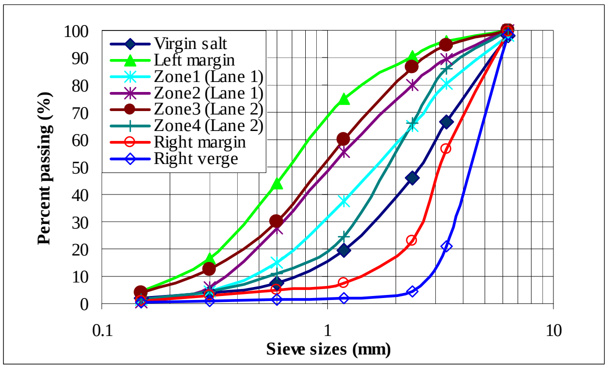
(b) Econ Zero C Mk 4 – 2002 model, 3mm salt



(c) Epoke Sirius SH3500, 6.3mm salt



(d) Modified Schmidt Stratos B90, 6.3mm salt



(e) Giletta 80501D, 6.3mm salt

Figure A.7 Salt particle size distributions