Agricultural Development and Advisory Service


Report to: Horticultural Development Council
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CONTRACT REPORT

No. AR/91/10

# Onions - Prevention of early Manganese Deficiency

Undertaken on Behalf of HDC.

HDC Ref No FV/79

Commercial - In Confidence

ADAS

**PRINCIPAL WORKER**

Julian Davies BSc Horticultural Advisor (author of report)

**AUTHENTICATION**

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

..... C.S.Speller ..... Date 16.1.92

Colin Speller Contract Manager

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.....

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## ONIONS - PREVENTION OF EARLY MANGANESE DEFICIENCY


### Summary

The placement of specific fertilisers to overcome manganese deficiency in onions was evaluated. Mono-ammonium phosphate and manganese sulphate were each applied as a band of fertiliser in a furrow directly below a drilled row of onions cv Hysam. All combinations of mono-ammonium phosphate (12:61:0) at 213 kg/ha and manganese sulphate at either 3 or 30 kg/ha were tested with half of the trial also receiving foliar sprays of manganese sulphate at 9 kg in 300 l/ha water on 9 and 30 May, 17 June, 8 July and 7 August.

The early vigour of the onions was significantly increased where mono-ammonium phosphate had been applied prior to drilling. No additional benefit was found from including manganese sulphate in the furrow or applying it after crop emergence. This increased vigour continued through the whole season. No visual signs of manganese deficiency were observed. At harvest on 17 September the plant populations were similar with an average of 40 plants/$m^2$. The mean total yield was 37.9 t/ha with a significant increase where mono-ammonium phosphate had been applied prior to drilling. There was no benefit from the manganese sulphate applications. The mean yield of onions over 50 mm was 32.1 t/ha with a significant increase in yield where mono-ammonium phosphate had been applied (35.5 compared to 28.8 t/ha). There was again no benefit from applying manganese sulphate either with the mono-ammonium phosphate or as routine sprays after crop emergence. The number of thicknecked bulbs was reduced from 7.1 to 3.0% following the placement of mono-ammonium phosphate in a band beneath the seed. This improvement in vigour and yield could be due to the increased quantity of nitrogen and phosphate in the rooting zone or to the increased localised acidity caused by the mono-ammonium phosphate.

## Introduction

Manganese deficiency is very common on peats and some other soils particularly where pH is as high as 7.0. Routine applications of manganese sulphate or chelated manganese compounds are made once the crop has enough leaf area to absorb the sprays. Several applications are usually required during the earlier growth stages when frequent low-rate herbicide sprays are also needed. These combinations of chemicals can cause crop damage and the resulting loss in vigour can make the plant more susceptible to weather damage and increase the incidence of thicknecked bulbs at harvest.

A technique has been developed in Canada and North America whereby mono-ammonium phosphate and manganese sulphate are placed in a band between 5 and 8 cm below the seed. The mono-ammonium phosphate acidifies the adjacent soil and it is thought that this then allows the developing root system to take up the manganese more effectively. This lessens the risk of manganese deficiency occurring and also avoids at least three tractor applications of manganese sulphate.

This trial was designed to evaluate the technique using an identical rate of mono-ammonium phosphate to that used abroad. Two rates of manganese sulphate were used, one currently used in Canada and a lower rate which is equivalent to the quantity of manganese found in crops at harvest. Half of the trial received post-emergence sprays of manganese sulphate. The effect of the treatments on crop vigour, yield and bulb quality at harvest was assessed.

## Objective

To assess the potential benefit of placing mono-ammonium phosphate and manganese sulphate below the seed to prevent manganese deficiency and to avoid the need for routine foliar applications of manganese sulphate after crop emergence.

## Materials and Methods

### Site

The trial was conducted on Owens Piece field at ADAS Arthur Rickwood, Mepal, Ely, Cambridgeshire. The soil type was a peaty loam 36-66 cm deep with 29% organic matter content over a silty clay loam. The field was selected because manganese deficiency has often been observed there in the past.

### Treatments

1. Application of mono-ammonium phosphate (MAP)
   a. Nil
   b. 213 kg/ha (12:61:0) placed as a band 5-8 cm beneath the seed

2. Application of manganese sulphate
   a. Nil
   b. 3 kg/ha placed as a band 5-8 cm beneath the seed
   c. 30 kg/ha placed as a band 5-8 cm beneath the seed

3. Post emergence sprays
   a. None
   b. Routine manganese sulphate spray programme, at 9 kg/300 l/ha water + Agral at 0.75 l/1000 l of water

All combinations were carried out with a total of 12 treatments.

### Husbandry

Four furrows were made in each bed to a depth of 7-9 cm and the materials applied uniformly along the bottom of each one. The furrows were then filled in with adjacent soil and lightly firmed. A Stanhay drill was then used to drill the four rows of onions on each bed using the cultivar Hysam.

The trial received standard insecticide, herbicide and fungicide inputs according to good field practice. These are detailed in Appendix I. The

post-emergence sprays of manganese sulphate were applied as appropriate on 9 and 30 May, 17 June , 8 July and 7 August using a hand held Oxford Precision sprayer at 2 bar pressure with Teejet '8002' nozzles.

The trial was harvested at the 80% foliage fall over stage and loaded into store for drying and curing. After a period of storage the trial was graded.

Assessments

1. Onion vigour assessment on 7 April.
2. Plant populations on 7 April (based on 1.68 $m^2$).
3. Onion vigour assessment on 12 June.
4. Plant populations and yield at harvest (based on 10.08 $m^2$).
5. Quality and defects at harvest.

Design

A randomised block design was used with three replicates. Each plot comprised a 1.68 m bed and was 6 m in length (10.08$m^2$). Four rows of onions were drilled at a 350-250-350 mm spacing to allow a barley shelter crop to be established between the two outer rows on either side of the bed.

Statistical analysis

All the data was subjected to a three way factorial analysis of variance. The number of defects, expressed as percentage were transformed to improve the accuracy of the analysis. The yields in the various size grades were analysed seperately with a minimum diameter of 50 mm selected due to market specification.

## Results

The onions emerged in the second week of April at a similar time to the barley shelter crop. The plant populations were assessed on 7 April, and were meaned across the post-emergence sprays as by this date no sprays had actually been applied.

Table 1. Plant populations (plants/$m^2$) on 7 April.

| Manganese sulphate treatment | Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 45 | 44 | 44 |
| 3 kg/ha | 48 | 48 | 48 |
| 30 kg/ha | 39 | 46 | 42 |
| Mean | 44 | 46 | 45 |

| | |
|---|---|
| CV % | 20 |
| SED (22 df) for comparing rates of MAP | 3.0 |
| SED (22 df) for comparing rates of manganese sulphate | 3.7 |

The emergence was quite patchy which affected this assessment. However, it does appear that the application of 30 kg/ha of manganese sulphate in the furrow did reduce the number of plants.

The first vigour assessment was taken on 7 April and again meaned across the post-emergence spray treatments, Table 2.

Table 2. Onion vigour on 7 April.

| Manganese sulphate treatment | Vigour of onions (0-10)* Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 5.3 | 7.6 | 6.4 |
| 3 kg/ha | 5.0 | 8.1 | 6.5 |
| 30 kg/ha | 4.8 | 7.3 | 6.1 |
| Mean | 5.0 | 7.7 | 6.4 |

| | |
|---|---|
| CV % | 16 |
| SED (22 df) for comparing rates of MAP | 0.34 |
| SED (22 df) for comparing rates of manganese sulphate | 0.42 |

* 0 = dead; 3 = yellow, short; 7 = green, slight leaf tipping; 10 = green, upright vigorous

There was a significant ($P<0.05$) improvement in vigour where MAP had been applied in the furrow. There appeared to be no benefit in applying manganese sulphate in the furrow with MAP.

The second vigour assessment was taken on 12 June, following the first two manganese foliar applications, Table 3.

Table 3. Onion vigour on 12 June.

| Treatment | Vigour of onions (0-10)* Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 5.7 | 8.0 | 6.8 |
| $MnSO_4$ @ 3 kg/ha | 6.3 | 7.7 | 7.0 |
| $MnSO_4$ @ 30 kg/ha | 5.0 | 8.0 | 6.5 |
| Mean | 5.7 | 7.9 | 6.8 |
| Nil + sprays | 5.8 | 7.3 | 6.6 |
| $MnSO_4$ @ 3 kg/ha + sprays | 5.7 | 7.7 | 6.7 |
| $MnSO_4$ @ 30 kg/ha + sprays | 6.0 | 7.7 | 6.8 |
| Mean | 5.8 | 7.6 | 6.7 |
| Overall mean | 5.8 | 7.7 | 6.7 |

* see previous table for scoring key

| | |
|---|---|
| CV % | 11 |
| SED (22 df) for comparing rates of MAP | 0.25 |
| SED (22 df) for comparing rates of manganese sulphate | 0.31 |
| SED (22 df) for comparing spray treatments | 0.25 |

There was a significant ($P<0.05$) improvement in vigour where MAP had been applied in the furrow prior to drilling. There appeared to be neither a benefit from applying the manganese sulphate to the furrow nor to its use as post-emergence sprays.

Following a period of storage the onions were counted and graded. The number of plants is given in Appendix II.

All treatments were found to have similar plant populations at harvest despite differences observed earlier in the season (Appendix II).

The yield of bulbs over 50 mm in diameter is given in Table 4 with total yield and yield of bulbs over 60 mm given in Appendix III and IV, respectively.

Table 4. Yield (t/ha) of bulbs over 50 mm.

| Treatment | Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 32.4 | 41.8 | 37.1 |
| $MnSO_4$ @ 3 kg/ha | 32.3 | 33.8 | 33.0 |
| $MnSO_4$ @ 30 kg/ha | 27.1 | 37.5 | 32.3 |
| Mean | 30.6 | 37.7 | 34.2 |
| Nil + sprays | 29.2 | 30.0 | 29.6 |
| $MnSO_4$ @ 3 kg/ha + sprays | 21.7 | 34.7 | 28.2 |
| $MnSO_4$ @ 30 kg/ha + sprays | 30.2 | 35.0 | 32.6 |
| Mean | 27.0 | 33.2 | 30.1 |
| Overall mean | 28.8 | 35.5 | 32.1 |

| | |
|---|---|
| CV % | 17 |
| SED (22 df) for comparing rates of MAP | 2.21 |
| SED (22 df) for comparing rates of manganese sulphate | 1.81 |
| SED (22 df) for comparing spray treatments | 1.81 |

The placement of MAP in the furrow prior to drilling significantly ($P<0.05$) increased yield. There appeared to be no benefit from applying manganese sulphate to either the furrow or routinely during the life of the crop.

A similar result was also observed for both the total yield and for the yield of bulbs over 60 mm.

The quality of bulbs was generally very good with low levels of defects. The main defect was thicknecked bulbs, Table 5.

Table 5. Number of thicknecked bulbs (%) - angular transformations in parenthesis for statistical comparison.

| Treatment | Rate of MAP Nil | | 213 kg/ha | | Mean | |
|---|---|---|---|---|---|---|
| Nil | 3.6 | (10.2) | 1.7 | ( 7.0) | 2.7 | ( 8.6) |
| $MnSO_4$ @ 3 kg/ha | 3.3 | (10.3) | 2.1 | ( 8.4) | 2.7 | ( 9.3) |
| $MnSO_4$ @ 30 kg/ha | 11.4 | (19.6) | 2.3 | ( 8.4) | 6.8 | (14.0) |
| Mean | 6.1 | (13.3) | 2.0 | ( 7.9) | 4.1 | (10.6) |
| Nil + sprays | 7.1 | (15.2) | 4.8 | (12.6) | 6.0 | (13.9) |
| $MnSO_4$ @ 3 kg/ha + sprays | 9.7 | (16.2) | 4.6 | (11.5) | 7.2 | (13.9) |
| $MnSO_4$ @ 30 kg/ha + sprays | 7.6 | (15.8) | 2.8 | ( 8.6) | 5.2 | (12.2) |
| Mean | 8.2 | (15.7) | 4.0 | (10.9) | 6.1 | (13.3) |
| Overall mean | 7.1 | (14.5) | 3.0 | ( 9.4) | 5.1 | (12.0) |

| | |
|---|---|
| CV % | 39 |
| SED (22 df) for comparing rates of MAP | 1.57 |
| SED (22 df) for comparing rates of manganese sulphate | 1.93 |
| SED (22 df) for comparing spray treatments | 1.57 |

The use of MAP significantly ($P<0.05$) reduced the number of thicknecked bulbs. Neither the addition of manganese sulphate in the furrow or its use as routine sprays post-emergence reduced the incidence of this defect.

## Discussion

The in-furrow placement of mono-ammonium phosphate and manganese sulphate did not affect the final plant stand of the crop as at harvest all the treatments had similar plant populations. Mono-ammonium phosphate did improve early vigour and this was maintained throughout the season and resulted in a higher total yield at harvest, with more bulbs in the larger size grades. The addition of manganese sulphate either in the furrow or applied routinely after crop emergence did not increase plant vigour and at harvest the yields were similar to where no manganese has been used. This would tend to suggest that the increased vigour and yield associated with the use of mono-ammonium phosphate might be due to the extra 25.6 kg/ha N and 129.9 kg/ha $P_2O_5$ given to the plants but it could also be related to the slight localised increase in acidity caused by the MAP which could allow release of manganese naturally occurring in the soil.

## Conclusions

1. The placement of mono-ammonium phosphate in a band about 5 cm below the seed improved plant vigour, increased total yield and yield in the larger size grades. The number of thicknecked bulbs was also reduced.

2. The placement of manganese sulphate in the furrow with the mono-ammonium phosphate did not enhance the effect.

3. Post-emergence spray applications of manganese sulphate from 9 May to 7 August had no effect on plant vigour or yield.

## Recommendations

The trial has identified that placement of mono-ammonium phosphate below the seed can improve yield. However, further work is required to determine whether this is due to the extra nitrogen and phosphate in the root zone or due to some other effect. For these reasons the trial should be repeated and the site selected which is again known to have a history of manganese deficiency.

Storage of data

The data will be stored at ADAS Arthur Rickwood, Mepal, Ely, Cambridgeshire for a period of 10 years. The Horticultural Development Council will be consulted before its disposal.

## Appendix I

| | | |
|---|---|---|
| Field | Owens Piece | |
| Previous cropping | 1990 | Sugar beet |
| | 1989 | Winter wheat |
| | 1988 | Winter wheat |
| Crop diary | | |
| Cultivations | 20 December | ploughed and furrow pressed |
| | 11 March | cultivated using rotary harrow |
| Husbandry | 13 March | drilled using Stanhay drill |
| | 25 March | barley shelter drilled |
| | 18 June | trial hoed |
| Herbicides | 3 April | 4.32 kg/ha ai propachlor + 2.24 kg/ha ai chlorpropham + 0.6 kg/ha paraquat as 9 l/ha cp Ramrod Flo + 5.6 l/ha cp CICP + 3 l/ha cp Gramoxone in 600 l/ha water |
| | 3 May | 0.45 kg/ha ai chlorbufam + 0.56 kg/ha ai chloridazon as 2.25 l/ha cp Alicep in 500 l/ha water |
| | 20 May | 0.042 kg/ha ai fluazifop-P-butyl as 0.3 l/ha cp Fusilade in 250 l/ha water + Agral at 1 l/1000 l of water |
| | 4 June | 0.125 kg/ha ai fluazifop-P-butyl as 1.0 l/ha cp Fusilade in 500 l/ha water + Agral at 1 l/1000 l of water |
| | 10 July | 2.88 kg/ha ai propachlor as 6 l/ha cp Ramrod Flo in 400 l/ha water |
| | 16 July | 1.75 kg/ha ai cyanazine as 3.5 l/ha cp Fortrol in 400 l/ha water |
| Insecticides | 13 March | 2.8 kg/ha ai carbofuran as 28 kg/ha cp Yaltox applied at drilling |
| | 31 July | 7.5 ml/ha ai deltamethrin as 0.3 l/ha cp Decis in 1000 l/ha water |
| | 21 August | as above |
| Fungicides | 25 July | 1.0 kg/ha ai chlorothalonil as 2.0 l/ha cp Bravo + 280 mls/ha cp Bond in 200 l/ha water |
| Irrigation | 10 June | 25 mm |
| | 13 July | 25 mm |
| | 27 August | 25 mm |

| | | |
|---|---|---|
| Fertiliser | 4 December | 80 kg/ha $P_2O_5$ + 120 kg/ha $K_2O$ |
| | 4 April | 40 kg/ha N |
| | 7 May | 40 kg/ha N |
| Trace elements | 9 May | 9 kg manganese sulphate in 300 l/ha water as appropriate |
| | 30 May | 9 kg manganese sulphate in 300 l/ha water as appropriate |
| | 17 June | 9 kg manganese sulphate in 300 l/ha water as appropriate |
| | 8 July | 9 kg manganese sulphate in 300 l/ha water as appropriate |
| | 7 August | 9 kg manganese sulphate in 300 l/ha water as appropriate |
| | 9 August | 8 kg/ha Epsom salts in 300 l/ha water (whole trial) |
| | 19 August | as above |
| Harvest | 17 September | |
| Graded out of store | 27 October | |

## Appendix II

Plant populations at harvest (plants/$m^2$).

| Treatment | Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 41 | 42 | 42 |
| $MnSO_4$ @ 3 kg/ha | 45 | 42 | 43 |
| $MnSO_4$ @ 30 kg/ha | 37 | 41 | 39 |
| Mean | 41 | 42 | 41 |
| Nil + sprays | 36 | 39 | 38 |
| $MnSO_4$ @ 3 kg/ha + sprays | 47 | 39 | 43 |
| $MnSO_4$ @ 30 kg/ha + sprays | 36 | 36 | 36 |
| Mean | 40 | 38 | 39 |
| Overall mean | 40 | 40 | 40 |

| | |
|---|---|
| CV % | 17 |
| SED (22 df) for comparing rates of MAP | 2.8 |
| SED (22 df) for comparing rates of manganese sulphate | 2.3 |
| SED (22 df) for comparing spray treatments | 2.3 |

All treatments had similar plant populations at harvest.

Appendix III

Total yield (t/ha).

| Treatment | Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 38.4 | 46.4 | 42.4 |
| $MnSO_4$ @ 3 kg/ha | 39.8 | 40.1 | 39.9 |
| $MnSO_4$ @ 30 kg/ha | 31.4 | 43.1 | 37.3 |
| Mean | 36.5 | 43.2 | 39.9 |
| Nil + sprays | 33.6 | 36.8 | 35.2 |
| $MnSO_4$ @ 3 kg/ha + sprays | 32.4 | 39.3 | 35.9 |
| $MnSO_4$ @ 30 kg/ha + sprays | 34.5 | 39.4 | 37.0 |
| Mean | 33.5 | 38.5 | 36.1 |
| Overall mean | 35.0 | 40.9 | 37.9 |

| | |
|---|---|
| CV % | 15 |
| SED (22 df) for comparing rates of MAP | 1.9 |
| SED (22 df) for comparing rates of manganese sulphate | 2.4 |
| SED (22 df) for comparing spray treatments | 1.9 |

**Appendix IV**

Yield (t/ha) of bulbs over 60 mm in diameter.

| Treatment | Rate of MAP Nil | 213 kg/ha | Mean |
|---|---|---|---|
| Nil | 15.4 | 28.2 | 21.8 |
| $MnSO_4$ @ 3 kg/ha | 15.9 | 20.6 | 18.3 |
| $MnSO_4$ @ 30 kg/ha | 13.2 | 22.9 | 18.1 |
| Mean | 14.8 | 23.9 | 19.4 |
| Nil + sprays | 15.6 | 16.0 | 15.8 |
| $MnSO_4$ @ 3 kg/ha + sprays | 6.9 | 21.2 | 14.1 |
| $MnSO_4$ @ 30 kg/ha + sprays | 17.7 | 25.4 | 21.5 |
| Mean | 13.4 | 20.1 | 17.1 |
| Overall mean | 14.1 | 22.4 | 18.3 |

| | |
|---|---|
| CV % | 31 |
| SED (22 df) for comparing rates of MAP | 1.91 |
| SED (22 df) for comparing rates of manganese sulphate | 2.34 |
| SED (22 df) for comparing spray treatments | 1.91 |

Appendix V

Contract between ADAS (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

## PROPOSAL

**1. TITLE OF PROJECT** **Contact No: FV 79**

BULB ONIONS: PREVENTION OF EARLY MANGANESE DEFICIENCY

**2. BACKGROUND AND COMMERCIAL OBJECTIVE**

Manganese deficiency is very common on peaty and some other soils particularly where pH is as high at 7.0. Routine applications of manganese sulphate or chelated manganese compounds are made once the crop has enough leaf area to target the sprays. However, manganese deficiency often occurs very early in the life of the crop, causing a loss of vigour that, even if it goes unnoticed, will make the plant more susceptible to both weather and herbicide damage, delay maturity and increase the incidence of thicknecked bulbs at harvest. In Canada an idea from Michigan is being adopted (see "MAFF Study Tour Report of visit to Ontario Canada by Peter Rickard"). This idea seeks to reduce the pH of the soil near the seed and seedling so that the crop can make better early growth. This is achieved by applying a band of 46 kg/ha (250 lb/acre) of mono ammonium phosphate (18-46-0) + 9 kg/ha (50 lb/acre) of manganese sulphate at approximately 5-7 cm (2-3 inches) below the seed using a disc coulter and cover on the front of the seeder. These acid fertilisers help to keep the manganese in solution and available to the crops. The balance of fertilisers are broadcast in the normal way. The report states that 'commercial strips of the treatment appeared to produce quite staggering results.'

Details of the technique and equipment used have been recently received from Canada. The first year will be a simple look-see into the scope for using mechanical equipment to exactly place the chemicals, and to assess potential benefit of such placement.

Note:
Canadian researchers suggest the technique also benefits the crop by encouraging early uptake of Phosphate (due to localised depression of the pH around the root zone). If the work seems promising in its first year HDC may make provision to develop the technique to other crops/soil types in 1992.

**3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY**

More uniform and reliable establishment, more vigorous early growth, less susceptibility to wind or herbicide damage, better yields and bulb quality. This slight improvement in crop vigour could lead to bulbs achieving a greater average size. If the number of later applications of manganese could be reduced then this would save field

work. Young plants growing at their peat performances will use other expensive inputs of water and nutrients more effectively.

In Canada there are claims of 30% yield increases with accurate placement of manganese fertilisers plus acidifying chemicals.

## 4. SCIENTIFIC/TECHNICAL TARGET OF WORK

1. To investigate the optimum rates of both mono ammonium phosphate and manganese sulphate.

2. To study mechanical system(s) for accurate depth of placement (eg equipment used at HRI Wellesbourne).

3. To determine whether this technique could prevent the need for three or more later applications of manganese sprays.

## 5. CLOSELY RELATED WORK COMPLETED OR IN PROGRESS

Starter fertiliser work at HRI (W) and (K). Fertiliser placement in bands at Kirton. Similar work on sugar beet at Terrington EHF and Morley Research Centre. Extensive trials work on this subject in Canada from where the idea originated.

## 6. DESCRIPTION OF WORK

A crop of onions would be established on a field known to suffer severe manganese deficiency. In the first instance tractor mounted equipment will be used to apply mono ammonium phosphate and manganese sulphate at the 'optimum' depth. Further work will investigate rates of mono ammonium phosphate and manganese sulphate to identify the most promising combination for early crop growth.

## 7. COMMENCEMENT DATE AND DURATION

February 1991, for one season (data completed by January 1992).

## 8. STAFF RESPONSIBILITIES

Experiment Leader - Sally R Runham
Contract Manager - C S Speller

## 9. LOCATION

Arthur Rickwood EHF

## 10. COSTS

The cost to HDC will be £3250

## 11. PAYMENT

On each quarter day the Council will pay the Contractor in accordance with the following schedule:

| Quarter/Year | 1991 | 1992 |
|---|---|---|
| 1 | 543 | 271 |
| 2 | 812 | - |
| 3 | 812 | - |
| 4 | 812 | - |

## TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor (s)

Signature.....

Position R&D Manager

Date 22/4/91

Signed for the Contractor (s)

Signature.....

Position.....

Date.....

Signed for the Council

Signature.....

Position CHIEF EXECUTIVE

Date 19.4.91