Material change for
a better environment

Plasterboard technical report

# Recycled gypsum as a soil treatment in potato production

An evaluation of the use of recycled gypsum from waste plasterboard for improving soils for the commercial growing of potatoes.

**Project code:** PBD0070021
**Research date:** December 2005 – November 2006
**ISBN:** 1-84405-324-5
**Date:** June 2007

**Front cover photograph:** Baking potatoes grown in agricultural soil conditioned with recycled gypsum



Published by
**Waste & Resources Action Programme**

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

# Context

## WRAP

WRAP (Waste & Resources Action Programme) works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.

Established as a not-for-profit company in 2000, WRAP is backed by Government funding from Defra and the devolved administrations in Scotland, Wales and Northern Ireland.

## WRAP and plasterboard

Through its Construction Programme, WRAP is helping the construction industry cut costs and increase efficiency through the better use of materials.

Plasterboard is used extensively in the construction and refurbishment of buildings as a lining for walls and ceilings, and for forming structures such as partitions.

Plasterboard waste can arise on construction sites for a number of reasons, including wasteful design, off-cuts from its installation, damaged boards, and over-ordering. It is estimated that over 300,000 tonnes per year of waste plasterboard is produced on construction sites. It can also arise from strip-out activities during refurbishment and demolition projects; the waste arisings from this source are significantly higher. In total it is estimated that over one million tonnes of waste plasterboard are produced each year from construction and demolition activities.

Most of this waste is currently disposed to landfill, even though it can be easily recycled. WRAP receives funding from Defra through the Business Resource Efficiency and Waste (BREW) programme to divert plasterboard waste from landfill by working to overcome the barriers to plasterboard recycling. Additional funding is also received from the devolved administrations in Scotland, Wales and Northern Ireland.

WRAP is working to overcome the barriers through the following key areas:

- plasterboard waste minimisation;
- site waste management;
- segregation and collection of plasterboard waste;
- development of infrastructure, including waste logistics and recycling capacity;
- market development for materials from plasterboard recycling – recycled gypsum and reclaimed paper;
- education, awareness and behavioural change; and
- informing and influencing legislation, regulations and policy.

More information on WRAP's work can be found at www.wrap.org.uk/construction

# Executive summary

## Objectives

Over one million tonnes of waste plasterboard are estimated to be produced each year in the UK from construction and demolition activities. Most of this waste is currently sent to landfill, even though it can be recycled. WRAP is working to divert plasterboard waste from landfill by seeking to overcome the barriers to plasterboard recycling. One area of its work is to develop markets for the materials from plasterboard recycling (recycled gypsum and reclaimed paper), and use of recycled gypsum in agriculture has been identified as a market with significant potential.

Adding gypsum to agricultural arable soils is a traditional way of improving soil condition. Gypsum supplied for this purpose is usually mined or quarried, which also depletes natural resources. This study was undertaken to evaluate whether recycled gypsum produced from waste plasterboard is effective as a soil treatment in commercial potato production. A parallel study with winter wheat is due to report in early 2008. Both studies were undertaken by the research and development department of Velcourt Ltd.

The main effect on soil condition by adding gypsum was considered to be improved structure, leading to improved drainage and water-holding capacity, and the following benefits:

- the weather windows available for establishing, maintaining and harvesting the crop throughout the season should be widened, particularly when these processes involve intensive movements of heavy machinery; and
- hardness and cracking from compacted or baked soils should be reduced. This should lead to increased quality of the tubers through an improved soil structure reducing physical damage as the crop is harvested, and improved control of skin blemishes and tuber disfigurations. Improved quality could lead to higher premiums being paid to the grower.

It was also considered that as gypsum is calcium sulphate its application to soils could have the following additional benefits:

- aid restoration of calcium and sulphur deficiencies; and
- improve the efficiency of a plant's uptake of inorganic nitrogen fertiliser.

## The trial

The study comprised a trial within an arable field on a commercial farm in Suffolk which was producing quality potatoes (variety 'Estima') for a large supply contract in the pre-pack market. The cropping history of the field had had resulted in a sandy loam soil with minimal organic matter content that was structurally poor and was known to lie wet during winter months.

The trial area was divided into blocks. A randomised complete block design was used with four gypsum treatments (agricultural gypsum and recycled gypsum each at 3 and 6 tonnes per hectare [t/ha]) plus an untreated control. Once the gypsum was applied, normal farm practices continued to prepare the ground, plant the seed, and maintain and harvest the crop.

During the growing season a programme of inorganic ammonium nitrate fertiliser was applied at different rates between 126 and 300kgN/ha. This evaluated the extent to which the gypsum treatment improved the efficient of use of additional inorganic fertilisers by the plants.

A number of assessments were made before, during and after the trial to determine the effect of the treatments.

- Comparative crop yield from the different treatments was examined in terms of overall mass of unwashed and washed tubers, soil tare (mass of soil removed during washing), total tuber number, marketable yield fraction (proportion of crop suitable for its intended market) and weight of rotten tubers.
- Observations of common scab, netting, growth cracks and bloom were made as indicators of potato quality and skin finish – parameters that attract considerable scrutiny from buyers and consumers, and can affect the premiums paid to producers.

- Soil nutrient status and physical characteristics were assessed at the beginning and end of the trial to allow comparison of any changes in soil status as a result of the different gypsum treatments. The following measurements were made at both times:
  - pH;
  - standard soil nutrient availability indices (phosphate, potassium, magnesium);
  - cation exchange capacity;
  - cation exchangeable nutrients (calcium, magnesium, potassium, sodium); and
  - available plant soluble nutrients (calcium, sulphate, potassium, phosphate).

  In addition, soil dry bulk density was assessed at the end of the trial.

## Results and conclusions

Applying recycled gypsum to land used for potato production as part of a controlled trial was beneficial in its effects on the soil and the quality of the crop. The farmer involved in the trial was convinced of the benefits of recycled gypsum and intends to continue its use on his fields when required.

### Farming practice and crop safety

Standard spreading equipment can be used to apply recycled gypsum. No changes are required to the farming operations which follow – bed forming, planting, crop maintenance and harvest.

Recycled gypsum was applied to the soil at rate of up to 6t/ha without compromising the establishment of the crop. No phytotoxicity (injury, illness or damage caused to plants by materials such as fertilisers or pesticides) was observed in the potato crop at any time due to the presence of recycled gypsum.

### Potato harvesting and yield

The use of recycled gypsum as a soil conditioner did not provide any advantage in terms of increased yield and, in some cases, resulted in reductions in harvested yield mass and tuber quantity. However, this trial involved a single crop type grown on a single soil type and only two different gypsum application rates.

Adding gypsum had no effect on soil adhesion to the tubers. However, soil adhesion to the tubers from the untreated control was negligible as harvesting was carried out reasonably early and in good weather and soil conditions.

None of the gypsum soil treatments or different application rates had any affect on the proportion of total harvested yield that fell into the marketable yield fraction, whether measured by mass or tuber number. However, there was some evidence that fewer rotten tubers were collected from plots where recycled gypsum had been applied.

### Potato quality and tuber skin finish

The use of gypsum materials as soil conditioners had no effect on the occurrence or severity of common potato scab or potato skin netting.

However, the occurrence and severity of growth cracks in the tubers was significantly reduced. Recycled gypsum appeared to control the occurrence and severity of growth cracking at least as well as agricultural gypsum and, in some cases, achieved significantly better control.

Overall, observations of skin finish and bloom suggested that gypsum soil treatments can lead to a brighter and more marketable skin appearance.

### Soil quality

Applying gypsum did not reduce soil bulk density, though it was considered that soils with higher clay content could benefit more. It was also suggested that higher application rates or additional applications at similar rates over a sustained period might have a greater impact.

Similarly, soil pH remained unchanged. Because the host soil was already around pH 7, it was not possible to observe any neutralising effect of gypsum.

The availability of the major plant nutrients in the soil appeared to be relatively unaffected when gypsum was used. However, increased uptake cannot be ruled out as the gypsum may have prevented some loss of soluble nutrients through leaching and therefore made more available for use by the crop.

Recycled gypsum helped to increase the levels of available sulphate in the sandy loam soil, though not calcium levels. The trial showed that recycled gypsum is a viable alternative to agricultural gypsum when seeking to increase sulphate concentrations in soil.

### Potentially toxic elements

The levels of potentially toxic elements and heavy metals (with the exception of molybdenum) present in the recycled gypsum did not exceed those present in the agricultural gypsum. Agricultural gypsum can be supplied for unrestricted agricultural use, so recycled gypsum containing equal or lower levels of such elements could safely be substituted for it in similar applications. The levels of molybdenum found in the recycled gypsum were considerably lower than those permitted in sewage sludge applied to agricultural land.

### Economic assessment

The costs of using recycled gypsum in arable agriculture depend on a number of variable factors including the land area to be treated, the proximity of that land to the supplier or processor of the product, and the rate of gypsum to be applied. The price of recycled gypsum was found to be very competitive with that of agricultural gypsum, suggesting that choices are likely to be made based on local availability and haulage costs.

Figures from the trial farm suggest use of recycled gypsum may require an investment of around 1.5% of the market value of the potato crop removed and sold in a single season. The effects of gypsum treatment are likely to be seen in subsequent crops and pay back its direct costs over several years, depending on rate used and frequency of re-application. Even if the use of gypsum has only short-lived effects, the investment cost is likely to be justifiable if a consistent or higher quality crop is achieved, potentially leading to higher premiums for the grower.

## Potential aspects requiring further study

The following aspects were identified during the trial as meriting further study:

- the cost and effort involved in obtaining an exemption from the Waste Management Licensing Regulations for the application of recycled gypsum to agricultural land;
- methods of mitigating potential fugitive dust during the spreading of gypsum (it usually being a fine powder);
- the effects of factors such as soil type, rainfall, temperature and crop type; and
- the effect of different application rates.

With regard to the waste licensing aspect, work is currently underway to overcome this situation by the development of a Quality Protocol for recycled gypsum.  The intended effect of this document, should it be adopted by the Regulators, is that if the producer of recycled gypsum complies with its criteria then the user can use the product without the need for waste regulatory control.

# Contents

# 1.0 Introduction

Adding gypsum to agricultural arable soils is a traditional way of improving soil condition. Gypsum supplied for this purpose is usually mined or quarried. This study was undertaken to evaluate whether recycled gypsum produced from waste plasterboard is effective as a soil treatment in commercial potato production. A parallel study with winter wheat is due to report in early 2008. Both studies were undertaken by the research and development department of Velcourt Ltd.

The main consequence on soil condition by adding gypsum was considered to be improved structure. The effects this leads to – improved drainage and improved water-holding capacity – although seemly contradictory would actually be complementary by producing a more consistent moisture content in the soil. This was expected to lead to the following benefits.

- The weather windows for undertaking farming operations should be widened on soils that normally tend to lie wet. The soil should dry out sooner in the spring to allow machinery to travel on the land for establishing and maintaining the crop. It should be able to receive more rainfall before it becomes unfit for machinery to travel once again, enabling harvesting to occur later in the autumn. The harvesting process in particular can have a detrimental effect on the soil structure as intensive movement of heavy machinery (harvesters, tractors and trailers – Figure 1) is potentially destructive. It can be worse where soil structure is poor to begin with, leaving a compacted and smeared soil surface which requires restoration before further cropping. Adding gypsum to the soil should mitigate this damage.

**Figure 1** Equipment and vehicles used at potato harvest

- Hardness and cracking from compacted or baked soils should be reduced. This should lead to increased quality of the tubers because an improved soil structure would reduce physical damage as the crop is harvested. Liming the soil can achieve similar desirable physical changes, however the use of gypsum would be preferable as it should not adversely affect the control of potato scab. A more consistent moisture level in the soil should encourage more steady growth of the tubers so leading to reduced incidence of growth cracks. Scab and growth cracks are blemishes and disfigurations of the skin of the tubers that reduce quality and thus any premiums paid to producers.

It was also considered that as gypsum is calcium sulphate its application to soils could have the following additional benefits:
- aid restoration of calcium and sulphur deficiencies; and
- improve the efficiency of a plant's uptake of inorganic nitrogen fertiliser.

The study comprised a trial within an arable field on a commercial farm in Suffolk which was producing quality potatoes for a large supply contract in the pre-pack market. The cropping history of the field had had resulted in a soil that was structurally poor and was known to lie wet during winter months.

The trial area was divided into blocks, sub-divided into plots.  Some were left untreated, some treated with agricultural gypsum, and some with recycled gypsum;  two rates of gypsum treatment were used.  This design enabled the relative benefits of each treatment to be determined and compared.  A programme of variable rates of inorganic ammonium nitrate fertiliser was applied to the blocks to help to demonstrate the extent to which the addition of recycled gypsum improved the efficiency of use of additional inorganic fertilisers.

A number of assessments were made before, during and after the trial to determine the effect of the treatments, including:

- soil characteristics and nutrient status;
- crop growth and disease;
- yield, and
- tuber quality.

This report provides details of the trial undertaken, the results, assessments, and conclusions.  An economic assessment is included to demonstrate the viability of using recycled gypsum beneficially in commercial potato production.

### 1.1 Velcourt Ltd

Velcourt Ltd is a farm management company managing over 47,000 ha in the UK. The 77 farms within the business are managed as 38 enterprises with the equivalent number of farm managers. Approximately 75% of the area managed is put down each year to combinable crops. Velcourt Ltd advises clients on the management of a further 15,000 ha.

Velcourt's R&D department (Velcourt Ltd (R&D)) carries out field experiments on behalf of industry clients and government departments. Its work is independent and the company has a proven record in project management.

All trials work carried out by Velcourt Ltd (R&D) is completed to high quality standards following Standard Operating Procedures (SOPs). These SOPs document procedures followed when conducting trials work and are subject to continual review and periodic updating as required by the Pesticides Safety Directorate. The SOPs cover all trial activities and are kept at Velcourt Ltd (R&D) office in Cambridge for reference and training purposes.

The main members of the project team were:

- **Keith Norman** is the technical director of Velcourt Ltd and head of Velcourt Ltd (R&D). The department's role is to assist the farm management business by providing independent advice and support on crop production throughout the company. Keith is responsible for the company's crop production guidelines, farm manager training and technology transfer both within the company and also to external clients.

- **Paul Cartwright** is a field trials officer for Velcourt Ltd (R&D). His background is in environment management and agricultural research, including studies of sewage sludge applications to land. He divides his time between field trials of crop protection products and managing agronomic demonstrations on behalf of Velcourt Ltd, industry sponsors and other organisations for the annual Cereals Event (www.cerealsevent.org.uk).

## 2.0 Trial design

The trial was established on land under Velcourt Ltd's management on a farm near Woodbridge, Suffolk. Maps showing the location are included in Appendix A, together with a plan showing the trial location within the field.

The site chosen for the trial was land that had been cropped frequently with root crops and vegetables including potatoes, parsnips and onions. This had left the sandy loam soil with minimal organic matter content and it was now deemed to be structurally poor. The field is known to lie wet throughout the winter months, meaning late lifting of vegetables can compound structural problems as heavy farm traffic compacts and smears the soil. The field is unfit for subsequent tillage operations for extended periods, often into April.

The trial conformed to a randomised complete block design, with four replicates of each of four treatments and an untreated control, giving a total of 20 treatments (Table 1). Four blocks of the trial received a soil treatment of one of two different gypsum products at one of two different application rates measured in tonnes per hectare (t/ha). One block remained untreated as a control. Each block was split into 16 plots, each receiving one of four different total inorganic nitrogen fertiliser treatments over the four replicates.

- The trial was fully factorial, evaluating the use of recycled gypsum and comparing its benefits with mineral gypsum against an untreated control where nothing was added to the soil before crop establishment.
- A programme of variable rates of inorganic ammonium nitrate fertiliser was superimposed over the base applications of gypsum products. This helped to demonstrate the extent to which the addition of recycled gypsum improved the efficiency of use of additional inorganic fertilisers.
- Soil characteristics were measured before any field applications were made and again when the crop was harvested.
- Crop phytotoxicity and disease assessments were made in all plots as appropriate to identify differences in disease status varying with the soil conditions – in particular soil-borne diseases that affect potato crops.
- Plant count assessments were made in all plots to quantify claims that gypsum use can aid emergence.
- All plots were harvested to highlight yield differences. Post-harvest analysis was carried out to determine the physical characteristics of the crop and tuber quality for comparison.

**Table 1** Treatment protocol for potato trial

| Treatment | Gypsum soil treatment (before crop establishment) | | Inorganic nitrogen application | | |
|---|---|---|---|---|---|
| | Type | Amount (t/ha) | To seedbed (kgN/ha) | At tuber initiation (kgN/ha) | Total (kgN/ha) |
| 1 | Untreated control | – | 126 | 0 | 126 |
| 2 | Untreated control | – | 126 | 54 | 180 |
| 3 | Untreated control | – | 126 | 114 | 240 |
| 4 | Untreated control | – | 126 | 174 | 300 |
| 5 | Recycled gypsum* | 3 | 126 | 0 | 126 |
| 6 | Recycled gypsum | 3 | 126 | 54 | 180 |
| 7 | Recycled gypsum | 3 | 126 | 114 | 240 |
| 8 | Recycled gypsum | 3 | 126 | 174 | 300 |
| 9 | Recycled gypsum | 6 | 126 | 0 | 126 |
| 10 | Recycled gypsum | 6 | 126 | 54 | 180 |
| 11 | Recycled gypsum | 6 | 126 | 114 | 240 |
| 12 | Recycled gypsum | 6 | 126 | 174 | 300 |
| 13 | Agricultural gypsum† | 3 | 126 | 0 | 126 |
| 14 | Agricultural gypsum | 3 | 126 | 54 | 180 |
| 15 | Agricultural gypsum | 3 | 126 | 114 | 240 |
| 16 | Agricultural gypsum | 3 | 126 | 174 | 300 |
| 17 | Agricultural gypsum | 6 | 126 | 0 | 126 |
| 18 | Agricultural gypsum | 6 | 126 | 54 | 180 |
| 19 | Agricultural gypsum | 6 | 126 | 114 | 240 |
| 20 | Agricultural gypsum | 6 | 126 | 174 | 300 |

* Recycled gypsum derived from waste plasterboard.
† Natural mineral gypsum, marketed for agricultural use.

## 2.1 Materials specification

The recycled gypsum was predominantly calcium sulphate and was in dry powder/small aggregate form containing at least 75% product as particles <25 µm and a maximum particle size of 30 mm. It was obtained from Gypsum Recycling UK Ltd (GRUK) and is a product they supply for use in a number of applications, including the manufacturing of new plasterboard. The recycled gypsum was delivered in bulk bags (Figure 2).

The product was essentially free of paper and other physical contaminants such as wood, metal or plastics. Table 2 shows the specification for recycled gypsum as supplied by GRUK.

The agricultural gypsum was predominantly calcium sulphate dihydrate and was in dry powder form containing 80–98% product as particles <150 µm. It was obtained from British Gypsum/BPB Formula and was natural (mined) gypsum. The agricultural gypsum was delivered in 25 kg bags (Figure 3).

The product was stated to be 72–98% pure as calcium sulphate, with variations possible in accordance with natural variations in the source of raw mineral materials. The material was free from physical contaminants such as wood, metal or synthetic materials (e.g. plastics). Table 3 shows the typical grading specification for agricultural gypsum as stated on the data sheet.

**Figure 2** Recycled gypsum supplied in bulk bags

**Table 2** Typical specification for recycled gypsum (data supplied by GRUK)

| **Daily testing:** | **Requirement** |
|---|---|
| Free moisture | <10% by weight (with average maximum of 8%) |
| Purity (content of $CaSO_4.2H_2O$) | >90 weight % by weight |
| $Cl^-$(soluble) | <0.01 weight % by weight |
| **When exceeding the limits for Cl (soluble), the following should be controlled:** | |
| MgO | <0.05% by weight |
| $Na_2O$ | <0.05% by weight |
| $K_2O$ | <0.01% by weight |
| $F^-$(soluble) | <0.01% by weight |
| **Quarterly testing:** | |
| Cadmium (Cd) | <0.5 ppm |
| Lead (Pb) | <1.0 ppm |
| Mercury (Hg) | <0.5 ppm |
| Arsenic (As) | <1.0 ppm |
| Vanadium (V) | <25.0 ppm |
| Gypsum is to be free from asbestos, have a gamma index (radioactivity) <0.1 and have neutral odour. | |

**Figure 3** Agricultural gypsum supplied in pallets of 25kg bags

**Table 3** Typical grading specification for agricultural gypsum

| **British Standard sieve** | **% by weight retained** |
|---|---|
| 600µm | 2% maximum |
| +150 -300µm | 1.2 – 18% |
| 150µm | 80 – 98% |

## 2.2 Initial soil assessments

A number of soil assessments were carried out at the time of the trial establishment and repeated again towards the end of the project.

The analysis of soil nutrients and physical characteristics allowed comparisons to be made regarding any changes in soil status as a result of the addition of different gypsum treatments.

Soil samples were taken from the proposed site for the potato trial on 5 December 2005 and submitted for analysis. The results are shown in Table 4.

**Table 4** Soil nutrient assessment at proposed trial site, December 2005

| Parameter | | Untreated soil |
|---|---|---|
| pH | | 7.0 |
| Standard soil nutrient availability indices | Phosphate | 3 |
| | Potassium | 2 |
| | Magnesium | 2 |
| Cation exchange capacity (meq/100g) | | 9.1 |
| Cation exchangeable nutrients (%) | Calcium | 82.8 |
| | Magnesium | 13.1 |
| | Potassium | 3.2 |
| | Sodium | 0.8 |
| Available plant soluble nutrients (mg/l) | Calcium | 471 |
| | Sulphate* | 13 |
| | Potassium | 73 |
| | Phosphate | 90 |

Key: Very low – Low – Adequate – Excessive

* Value calculated back from original laboratory measurement of sulphur in different units (i.e. not a direct measurement).

The host field was identified as:

- Host Farm: Greenwell Farms, Gedgrave Hall, Woodbridge, Suffolk, IP12 2BX
- Field name: Stackyard T (near Tunstall, Suffolk)

Maps of the field location are given in Appendix A.

The trial was sited on a sandy loam soil rather than a heavy clay soil because the highest quality potato crops would not normally be grown on heavy soils as they will rarely, if ever, make the grade for the pre-pack market specifications.

This field was considered a suitable trial site as initial soil audit results identified it as land that, despite having sufficient total calcium, was deficient in sulphur and in functionally available calcium (i.e. calcium that is readily available for uptake by a crop). It was therefore expected to benefit from the addition of gypsum as one method of addressing imbalances in the soil nutrient status.

The soil analysis and trial location information was submitted to the Environment Agency on 6 January 2006 as part of the notification of an exempt activity of land treatment for agricultural benefit under the Waste Management Licensing Regulations 1994 (as amended). The exemption was registered on 31 January 2006.

## 2.3 Soil treatment applications

Following the harvest of the previous onion crop in late 2005, the soil of the trial field had been left with a large number of ruts and ridges caused by heavy farm traffic. A primary cultivation was carried out in early April 2006 before the gypsum was applied, to break up the surface and level out the topsoil in order to make spreading a more comfortable and accurate operation. The soil treatments were then applied on 5 April 2006.

A lime spreader (Figure 4) was used to apply the gypsum treatments. The spreader was calibrated to achieve an application rate of 3 tonnes per hectare (t/ha), with the same settings used for both the recycled gypsum and the agricultural (natural mineral) gypsum. Where the desired application rate was 6 t/ha, this was achieved by making two applications over the same block, each at the 3 t/ha rate.

**Figure 4** Spreading recycled gypsum on the trial area with a lime spreader

Following the successful application of the gypsum to the trial treatment blocks, the host farmer continued with the preparation of the seedbed in line with normal farm practice. This involved:

- incorporation of the gypsum (where applied) into the soil;
- formation of beds/ridges for planting; and
- application of fertilisers to the seedbed.

This work occurred before planting the crop.

## 2.4 Crop establishment

Following the gypsum applications the trial field was treated with compound fertiliser (Table 5). This was applied to the seedbed on 13 April 2006 before potato planting.

**Table 5** Composition of seedbed fertiliser

| Component | Application rate (kg/ha) |
|---|---|
| Nitrogen | 126 |
| Phosphate | 110 |
| Potassium | 315 |
| Magnesium oxide | 25 |
| Sulphur | 51 |

The crop in the field surrounding the trial area received a further 114 kg/ha nitrogen. The application was timed to coincide with the tuber initiation phase of plant growth and brought the fertiliser balance to 240 kgN/ha in total. The trial included treatments at this rate as well as variations both above and below this total application rate.

The potato variety planted throughout the field was Estima – a good all-round, multi-purpose potato grown for relatively early harvesting to supply baking potatoes to a large supermarket chain. The variety has some blight resistance and reasonable drought tolerance.

The crop was planted on 13 April 2006 in 91.5 cm wide ridges, with seed spaced 42.6 cm along each ridge.

## 2.5 Plant establishment

Establishment of a plant population of suitable size is essential to ensure the survival and development of sufficient tubers for good, optimal yield production. A number of factors can affect establishment and rooting ability including:

- climatic conditions;
- seed rate;
- seed quality (disease, dormancy, etc.); and
- seedbed conditions such as soil moisture, aeration and compaction.

With root crops, the establishment of appropriate plant populations directly affects the root growth characteristics and can affect the subsequent market acceptance of, in this instance, the potato yield. Where populations are too dense (i.e. seed spacing is short and germination is high), then competition for light at the canopy level and physical space for growth in the root zone can lead to higher numbers of small tubers – undesirable when growing baking potatoes. Conversely, where established populations are not dense enough, the yield can be reduced as space and light are being used sub-optimally. The fraction of large and oversize tubers in the harvested yield can also be higher due to excessive space being available in the root zone.

To establish whether the treatment of soil with recycled gypsum affected potato germination and establishment adversely or beneficially, the plant population that developed through to harvest was assessed (Table 6).

**Table 6** Table of means – potato plants established and survived through to crop harvest

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean plants per 8 m row |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 25.00 | 23.25 | 24.00 | 23.50 | **23.94** |
| 3 t/ha Recycled gypsum | 24.00 | 22.75 | 24.50 | 24.25 | **23.88** |
| 6 t/ha Recycled gypsum | 25.00 | 23.25 | 24.00 | 24.00 | **24.06** |
| 3 t/ha Agricultural gypsum | 23.50 | 24.00 | 23.25 | 23.25 | **23.50** |
| 6 t/ha Agricultural gypsum | 23.50 | 22.75 | 24.00 | 24.75 | **23.75** |
| **Mean plants per 8 m row** | **24.20** | **23.20** | **23.95** | **23.95** | Grand mean = **23.82** |

An analysis of variance test was carried out on the plant count data in Table 6 to determine if any differences in plant establishment and survival had occurred. The F-test probability (*P*) values for each treatment factor (gypsum soil treatment and total fertiliser treatment) and their interaction are shown below:

- Soil treatment (*P*)= 0.896
- Nitrogen rate applied (*P*)= 0.255
- Soil treatment × nitrogen rate (*P*)= 0.835

From this analysis, there was no evidence to suggest that the addition of recycled gypsum to the soil before planting had either a beneficial or adverse affect on the establishment or survival of potato plants (cv. Estima) on sandy loam soil.

## 2.6 Nitrogen dose-rate response

A small nitrogen dose rate response trial was included in the factorial design of the trial. This enabled data to be generated on the response of a commercial potato crop to inorganic nitrogen fertiliser which was comparable across the different soil treatments.

The details of the differential inorganic nitrogen treatments are shown in Table 1. The balance of fertiliser not incorporated into the seedbed was applied to the plots on 1 June 2006, within 24 hours of the field crop receiving its final treatment. This ensured that the trial treatments were in line with the host farm's operations and, as such, all data were representative of commercial farm practice.

## 2.7 Crop phytotoxicity

No phytotoxicity (injury, illness or damage caused to plants by materials such as fertilisers or pesticides) was observed in the potato crop at any time due to the presence of recycled gypsum being present in the soil.

Similarly, no phytotoxic effects were seen as a result of the application of agricultural gypsum or inorganic fertiliser to the soil or crop at any stage during the trial period.

# 3.0 Harvest

The potato trial was harvested on 18 August 2006 following haulm destruction using a flail topper three weeks previously. Potatoes were lifted from an 8-metre length of a single row in the centre of each plot.

All harvested tubers were collected and saved for grading (sorting by tuber size) and weighing. A sample of 100 tubers was taken from the marketable yield fraction of each plot (i.e. 45–85 mm grade). A further subsample of 50 tubers was taken and tuber quality was assessed.

A mechanised method of lifting potatoes from the trial plots was employed to simulate a commercial harvest as closely as possible. This was important to allow realistic observations to be made to determine whether use of recycled gypsum had any effect on soil adhesion on tubers.

A tractor-mounted single-row Ransomes potato lifter was employed which, when driven along a single row of potatoes, unearthed the tubers from their ridge effectively and then carried them over a metal web to separate them from the soil before dropping them back on the soil surface (Figure 5). All potatoes were collected into paper sacks and removed from the trial area before being graded and weighed.

Once potatoes had been harvested from all plots, subsamples were subjected to assessments of physical characteristics (i.e. tuber size and weight) as well as more subjective assessments regarding tuber quality (i.e. disease and skin finish). Analysis of variance (ANOVA) tests were conducted on all resulting data.

**Figure 5** Harvesting the potatoes from the trial

## 3.1 Potato yield results

A number of different measurements indicative of crop yield were carried out on the tubers from each of the 80 plots in the trial. The results of the analysis of variance tests – including tables of means, F-test probability (*P*) values and least significant difference (LSD) values – are presented below together with a brief explanation.

### *3.1.1 Overall mass of unwashed tubers*

The overall mass of unwashed tubers (Table 7) refers to the total combined mass of all tubers harvested from an 8-metre long ridge from an individual plot in the condition in which they were harvested.

**Table 7** Yield of potatoes per plot as harvested expressed as mass of unwashed tubers, in kg

| **Soil treatment** | **Total inorganic nitrogen rate applied (kgN/ha)** | | | | **Mean mass of unwashed tubers per plot** |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 39.03 | 41.23 | 45.20 | 44.10 | **42.39** |
| 3 t/ha Recycled gypsum | 35.40 | 40.40 | 39.90 | 42.12 | **39.46** |
| 6 t/ha Recycled gypsum | 36.27 | 37.60 | 40.38 | 38.87 | **38.28** |
| 3 t/ha Agricultural gypsum | 38.97 | 44.62 | 49.17 | 44.42 | **44.30** |
| 6 t/ha Agricultural gypsum | 39.48 | 40.77 | 45.98 | 48.43 | **43.66** |
| **Mean mass of unwashed tubers per plot** | **37.83** | **40.92** | **44.12** | **43.59** | Grand mean = **41.62** |

- Soil treatment (*P*)= 0.001 Least significant difference (LSD 5%) = 3.306
- Nitrogen rate applied (*P*)< 0.001 Least significant difference (LSD 5%) = 2.957
- Soil treatment × nitrogen rate (*P*)= 0.843

The recycled gypsum treatments achieved similar mean yield results at both 3 t/ha and 6 t/ha. The best overall yield appears to have been achieved from applying agricultural gypsum at 3 t/ha to the soil, though this was not significantly different to the overall yields achieved from potatoes grown in untreated soil.

Overall yields were seen to increase significantly as the total inorganic fertiliser rates were increased up to 240 kgN/ha. A further increase up to 300 kgN/ha applied fertiliser did not result in significantly different yields overall across the range of soil treatments.

### *3.1.2 Overall mass of washed tubers*

The overall mass of washed tubers (Table 8) refers to the total combined mass of all tubers harvested from an 8-metre long ridge from an individual plot following a given period of time in a potato washing machine to remove any soil adhering to the tubers.

**Table 8** Yield of potatoes per plot as harvested expressed as mass of washed tubers, in kg

| **Soil treatment** | **Total inorganic nitrogen rate applied (kgN/ha)** | | | | **Mean mass of washed tubers per plot** |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 34.98 | 40.70 | 45.00 | 43.58 | **41.06** |
| 3 t/ha Recycled gypsum | 26.22 | 29.95 | 39.40 | 41.38 | **34.24** |
| 6 t/ha Recycled gypsum | 36.27 | 37.58 | 40.15 | 39.32 | **38.33** |
| 3 t/ha Agricultural gypsum | 38.90 | 44.28 | 48.68 | 43.33 | **43.79** |
| 6 t/ha Agricultural gypsum | 39.00 | 40.93 | 45.57 | 47.90 | **43.35** |
| **Mean mass of washed tubers per plot** | **35.08** | **38.69** | **43.76** | **43.10** | Grand mean = **40.16** |

- Soil treatment (*P*)= 0.002 Least significant difference (LSD 5%) = 5.187
- Nitrogen rate applied (*P*)= 0.001 Least significant difference (LSD 5%) = 4.640
- Soil treatment × nitrogen rate (*P*)= 0.914

The recycled gypsum treatment at 3 t/ha achieved the lowest yield. This was a statistically significant reduction compared with yields achieved from untreated soil and where agricultural gypsum had been applied. All other soil treatments achieved statistically similar results.

Overall yields were seen to increase significantly as the total fertiliser rates were increased up to 240 kgN/ha. A further increase up to 300 kgN/ha applied fertiliser did not result in significantly different yields overall across the range of soil treatments.

### *3.1.3 Soil tare*

The soil tare (Table 9) refers to the mass of soil that is removed from the tubers when washed and can be indicative of the structure and characteristics of the soil in which a crop is grown. A high soil tare can represent difficult harvesting conditions and/or losses of topsoil (if significant amounts are removed from the field with the crop). It could possibly affect potato storage characteristics if soil adhered to the tubers traps moisture against the potato skin surface.

**Table 9** Soil tare expressed as mass of soil adhered to tubers which is removed when they are washed, in kg

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean soil tare |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 4.05 | 0.53 | 1.40 | 0.53 | **1.63** |
| 3 t/ha Recycled gypsum | 0.33 | 0.35 | 0.97 | 0.75 | **0.60** |
| 6 t/ha Recycled gypsum | 0.17 | 0.60 | 0.43 | 0.50 | **0.43** |
| 3 t/ha Agricultural gypsum | 0.56 | 0.63 | 0.97 | 1.67 | **0.96** |
| 6 t/ha Agricultural gypsum | 0.48 | 0.70 | 0.40 | 0.53 | **0.53** |
| **Mean soil tare** | **1.11** | **0.56** | **0.83** | **0.79** | Grand mean = **0.83** |

- Soil treatment (*P*)= 0.299
- Nitrogen rate applied (*P*)= 0.798
- Soil treatment × nitrogen rate (*P*)= 0.495

No significant differences in the soil tare were observed as a result of any soil or nitrogen treatment applied.

### *3.1.4 Total tuber number*

This refers to the total number of tubers lifted from each plot, i.e. an 8-metre length of a single ridge from the centre of a single plot (Table 10).

**Table 10** Tuber count (total number of tubers per plot)

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean tubers per plot |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 247.0 | 209.2 | 217.2 | 224.8 | **224.6** |
| 3 t/ha Recycled gypsum | 161.2 | 163.5 | 209.0 | 217.2 | **187.6** |
| 6 t/ha Recycled gypsum | 217.8 | 216.0 | 221.0 | 208.8 | **215.9** |
| 3 t/ha Agricultural gypsum | 232.5 | 233.8 | 241.2 | 228.8 | **234.1** |
| 6 t/ha Agricultural gypsum | 249.5 | 220.5 | 228.8 | 233.5 | **233.1** |
| **Mean tubers per plot** | **221.6** | **208.6** | **223.4** | **222.6** | Grand mean = **219.1** |

- Soil treatment (*P*)= 0.010 Least significant difference (LSD 5%) = 28.15
- Nitrogen rate applied (*P*)= 0.604
- Soil treatment × nitrogen rate (*P*)= 0.756

The number of tubers produced from soil treated with recycled gypsum at 3 t/ha was significantly lower statistically than produced by any other soil treatment or application rate. All other treatments and application rates achieved statistically similar results.

### *3.1.5 Marketable yield fraction*

Marketable yield fraction (Table 11) refers to the proportion of the crop grown that is most suitable for the market for which it is intended. In this case, the crop was destined for sale as baking potatoes where larger tubers are desirable (though not oversized ones). Profitability can be at risk if too high a percentage of the crop falls outside the marketable yield fraction.

For the purposes of this trial, the crop was graded using meshes of sizes 45 mm, 65 mm and 85 mm. The overall marketable yield was tubers that fell into the categories between 45 and 85 mm. Tuber mass and tuber numbers were recorded for each fraction.

**Table 11** Marketable yield of potatoes expressed as number of tubers of 45–85 mm grade

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean marketable tuber number |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 185.8 | 173.5 | 185.8 | 180.8 | **181.4** |
| 3 t/ha Recycled gypsum | 128.2 | 136.5 | 178.2 | 180.3 | **155.8** |
| 6 t/ha Recycled gypsum | 177.0 | 172.0 | 182.2 | 175.5 | **176.7** |
| 3 t/ha Agricultural gypsum | 185.2 | 192.5 | 202.5 | 189.0 | **192.3** |
| 6 t/ha Agricultural gypsum | 199.2 | 179.8 | 191.0 | 197.0 | **191.8** |
| **Mean marketable tuber number** | **175.1** | **170.8** | **187.9** | **184.5** | Grand mean = **179.6** |

- Soil treatment (*P*)= 0.016 Least significant difference (LSD 5%) = 23.05
- Nitrogen rate applied (*P*)= 0.319
- Soil treatment × nitrogen rate (*P*)= 0.854

There appears to have been a statistically significant reduction in the number of marketable tubers where recycled gypsum had been applied to the soil at a rate of 3 t/ha. All other treatments were statistically equal.

Further analysis of the potato yield results from the trial was carried out. Where data are expressed in percentage terms (Table 12), they have been included for information before being transformed in order to perform statistical analysis. Where ANOVA testing was applied to data expressed as percentages, it was subject to arcsine transformation to 'normalise' the dataset prior to analysis (Table 13).

**Table 12** Marketable yield of potatoes expressed as a percentage of total number of tubers harvested

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean marketable tuber fraction |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 75.22 | 82.94 | 85.66 | 80.67 | **81.13** |
| 3 t/ha Recycled gypsum | 79.52 | 83.59 | 85.14 | 83.14 | **82.85** |
| 6 t/ha Recycled gypsum | 81.25 | 79.33 | 82.47 | 84.13 | **81.80** |
| 3 t/ha Agricultural gypsum | 80.04 | 82.44 | 83.91 | 82.64 | **82.26** |
| 6 t/ha Agricultural gypsum | 80.20 | 81.57 | 83.49 | 84.53 | **82.45** |
| **Mean marketable tuber fraction** | **79.25** | **81.98** | **84.13** | **83.02** | Grand mean = **82.09** |

**Table 13** Marketable yield of potatoes analysed as percentage of total number of tubers harvested with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 0.853 | 0.979 | 1.032 | 0.943 | **0.952** |
| 3 t/ha Recycled gypsum | 0.924 | 0.990 | 1.020 | 0.983 | **0.979** |
| 6 t/ha Recycled gypsum | 0.951 | 0.918 | 0.971 | 1.001 | **0.961** |
| 3 t/ha Agricultural gypsum | 0.9320 | 0.971 | 0.996 | 0.974 | **0.968** |
| 6 t/ha Agricultural gypsum | 0.935 | 0.956 | 0.990 | 1.014 | **0.974** |
| **Mean** | **0.919** | **0.963** | **1.002** | **0.983** | Grand mean = **0.967** |

- Soil treatment ($P$)= 0.792
- Nitrogen rate applied ($P$)= 0.002 Least significant difference (LSD 5%) = 0.04252
- Soil treatment × nitrogen rate ($P$)= 0.542

No significant differences in the proportion of marketable tubers were observed as a result of any soil treatment applied during the trial.

The highest proportion of tubers falling into the marketable yield fraction were achieved from the application of 240 kgN/ha overall across the range of soil treatments. Significantly better results were achieved at this rate than at the lowest rate and there was no benefit in applying higher nitrogen rates.

Results for the mass of marketable potatoes are shown in Tables 14–16.

**Table 14** Mass of marketable potatoes expressed as mass of tubers of 45–85 mm grade

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean mass of marketable tubers |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 32.30 | 38.38 | 43.42 | 41.10 | **38.80** |
| 3 t/ha Recycled gypsum | 24.62 | 28.30 | 38.00 | 38.80 | **32.43** |
| 6 t/ha Recycled gypsum | 34.00 | 35.48 | 38.03 | 37.58 | **36.27** |
| 3 t/ha Agricultural gypsum | 36.15 | 41.55 | 46.33 | 40.90 | **41.23** |
| 6 t/ha Agricultural gypsum | 36.52 | 38.25 | 43.35 | 45.50 | **40.91** |
| **Mean mass of marketable tubers** | **32.72** | **36.39** | **41.82** | **40.77** | Grand mean = **37.93** |

- Soil treatment ($P$)= 0.004 Least significant difference (LSD 5%) = 5.012
- Nitrogen rate applied ($P$)< 0.001 Least significant difference (LSD 5%) = 4.482
- Soil treatment × nitrogen rate ($P$)= 0.925

There appears to have been a statistically significant reduction in the mass of marketable tubers where recycled gypsum was applied to the soil at a rate of 3 t/ha. All other treatments were statistically equal.

The highest mean mass of tubers making the marketable yield grade was achieved from the application of 240 kgN/ha overall across the range of soil treatments. Significantly better results were achieved at this rate than at either of the lower rates and there was no benefit in applying higher nitrogen rates.

**Table 15** Mass of marketable potatoes expressed as a percentage of total mass of tubers harvested

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean mass of marketable tubers |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 92.23 | 94.33 | 96.49 | 94.24 | **94.32** |
| 3 t/ha Recycled gypsum | 93.64 | 94.58 | 96.41 | 93.88 | **94.63** |
| 6 t/ha Recycled gypsum | 93.53 | 94.27 | 94.58 | 95.54 | **94.48** |
| 3 t/ha Agricultural gypsum | 92.78 | 93.93 | 95.16 | 94.36 | **94.06** |
| 6 t/ha Agricultural gypsum | 93.48 | 93.46 | 95.13 | 94.91 | **94.24** |
| **Mean mass of marketable tubers** | **93.13** | **94.12** | **95.55** | **94.58** | Grand mean = **94.35** |

**Table 16** Mass of marketable potatoes, analysed as a percentage of total mass of tubers harvested with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 1.176 | 1.233 | 1.308 | 1.234 | **1.238** |
| 3 t/ha Recycled gypsum | 1.220 | 1.246 | 1.304 | 1.221 | **1.248** |
| 6 t/ha Recycled gypsum | 1.214 | 1.234 | 1.248 | 1.271 | **1.242** |
| 3 t/ha Agricultural gypsum | 1.198 | 1.222 | 1.262 | 1.236 | **1.230** |
| 6 t/ha Agricultural gypsum | 1.214 | 1.208 | 1.261 | 1.255 | **1.234** |
| **Mean** | **1.205** | **1.229** | **1.277** | **1.243** | Grand mean = **1.238** |

- Soil treatment ($P$)= 0.924
- Nitrogen rate applied ($P$)= 0.003 Least significant difference (LSD 5%) = 0.03779
- Soil treatment × nitrogen rate ($P$)= 0.868

No significant differences in the proportion of mass of marketable tubers were observed as a result of any soil treatment applied during the trial.

The highest proportion of mass of marketable tubers was achieved from the application of 240 kgN/ha overall across the range of soil treatments. Significantly better results were achieved at this rate than at either of the lower rates and there was no benefit in applying increased nitrogen rates.

### *3.1.6 Rotten tubers*

All rotten tubers collected up with the harvested yield were recorded (Table 17).

**Table 17** Rotten tubers expressed as mass of rotten tubers collected with harvested yield in grams

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean mass of rotten tubers collected |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 0 | 134 | 22 | 48 | **51** |
| 3 t/ha Recycled gypsum | 18 | 0 | 0 | 0 | **4** |
| 6 t/ha Recycled gypsum | 0 | 10 | 0 | 0 | **2** |
| 3 t/ha Agricultural gypsum | 51 | 0 | 80 | 255 | **96** |
| 6 t/ha Agricultural gypsum | 40 | 42 | 93 | 86 | **65** |
| **Mean mass of rotten tubers collected** | **22** | **37** | **39** | **78** | Grand mean = **44** |

- Soil treatment ($P$)= 0.064
- Nitrogen rate applied ($P$)= 0.388
- Soil treatment × nitrogen rate ($P$)= 0.282

No significant differences in the mass of rotten tubers collected were observed as a result of any soil or nitrogen treatment applied during the trial. However, the F-test on the soil treatment gives a probability (*P*) value of 6.4%, which could indicate that a trend may be evident.

The mean values appear to show a very small mean mass of rotten tubers collected with the harvest yield samples from the trial plots where recycled gypsum had been applied to the soil and a seemingly much higher mass of rotten tubers collected with the harvest yield samples from plots where agricultural gypsum had been applied.

## 3.2 Potato quality and skin finish results

A number of different observations indicative of crop quality were made on the tubers from each of the 20 treatments in the trial. The results of the analysis of variance tests – including tables of means, F-test probability (*P*) values and least significant difference (LSD) values – are presented below together with a brief explanation.

In many instances, skin finish has little or no detrimental effect on the quality of the internal potato tissue. But from a marketing perspective, a bright and attractive skin finish is desirable and can affect premiums paid to producers. Visual appearance is heavily scrutinised by packers and consumers alike, and affects saleability in supermarkets.

### *3.2.1 Common scab*

Noticeable by the occurrence of a corky-textured, brown wart-like blemish on the skin of root crops (Figure 6), common scab is caused by a soil-borne organism that infects the epidermal layers of tubers and develops through the growth period between tuber initiation and crop harvest.

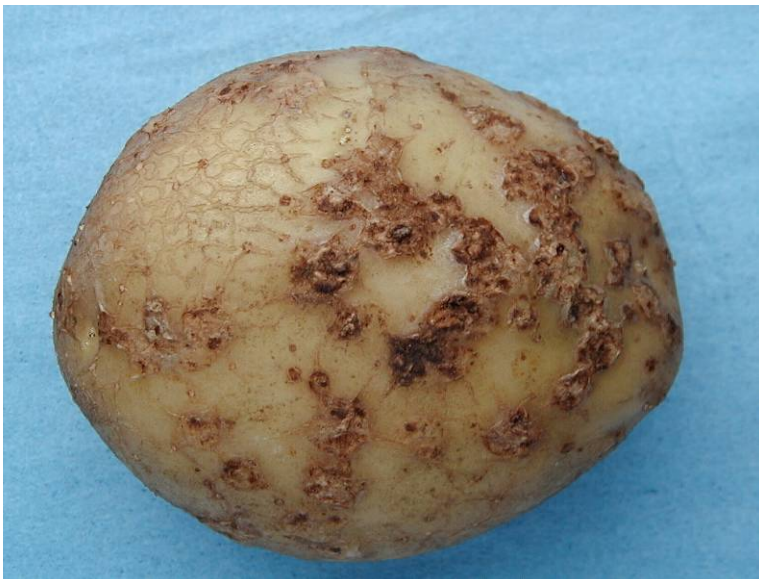


**Figure 6** Common scab

Photo: British Potato Council

The results of the trial analysis for common scab are presented in Tables 18–20.

**Table 18** Common scab incidence expressed as number of tubers exhibiting scab of a sample of 50 tubers

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean common scab incidence |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 1.00 | 1.00 | 4.67 | 4.00 | **2.67** |
| 3 t/ha Recycled gypsum | 1.01 | 2.00 | 1.67 | 2.00 | **1.67** |
| 6 t/ha Recycled gypsum | 4.00 | 4.00 | 4.33 | 2.33 | **3.67** |
| 3 t/ha Agricultural gypsum | 2.67 | 3.00 | 2.50 | 3.67 | **2.96** |
| 6 t/ha Agricultural gypsum | 1.00 | 0.00 | 1.00 | 2.33 | **1.08** |
| **Mean common scab incidence** | **1.94** | **2.00** | **2.83** | **2.87** | Grand mean = **2.41** |

- Soil treatment (*P*)= 0.230
- Nitrogen rate applied (*P*)= 0.718
- Soil treatment × nitrogen rate (*P*)= 0.952

No significant differences in the number of tubers displaying a scab of any size were observed as a result of any soil or nitrogen treatment applied during the trial.

**Table 19** Scab severity expressed as percentage of tuber surface area

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean common scab severity |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 0.023 | 0.043 | 0.143 | 0.110 | **0.080** |
| 3 t/ha Recycled gypsum | 0.010 | 0.025 | 0.047 | 0.023 | **0.026** |
| 6 t/ha Recycled gypsum | 0.090 | 0.053 | 0.070 | 0.057 | **0.068** |
| 3 t/ha Agricultural gypsum | 0.030 | 0.633 | 0.050 | 0.047 | **0.048** |
| 6 t/ha Agricultural gypsum | 0.133 | 0.000 | 0.017 | 0.027 | **0.044** |
| **Mean common scab severity** | **0.057** | **0.037** | **0.065** | **0.053** | Grand mean = **0.053** |

**Table 20** Scab severity analysed as percentage of tuber surface area with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 0.023 | 0.043 | 0.145 | 0.111 | **0.081** |
| 3 t/ha Recycled gypsum | 0.010 | 0.025 | 0.047 | 0.023 | **0.026** |
| 6 t/ha Recycled gypsum | 0.091 | 0.053 | 0.070 | 0.057 | **0.068** |
| 3 t/ha Agricultural gypsum | 0.030 | 0.637 | 0.050 | 0.047 | **0.048** |
| 6 t/ha Agricultural gypsum | 0.137 | 0.000 | 0.017 | 0.027 | **0.045** |
| **Mean** | **0.058** | **0.037** | **0.066** | **0.053** | Grand mean = **0.054** |

- Soil treatment (*P*)= 0.474
- Nitrogen rate applied (*P*)= 0.774
- Soil treatment × nitrogen rate (*P*)= 0.558

No significant differences in the size of scab lesions occurring on tuber skins were observed as a result of any soil or nitrogen treatment applied during the trial.

### *3.2.2 Netting*

Netting is the occurrence of a net-like pattern that develops on potato skins and is rough to the touch (Figure 7). Despite having no effect on the quality of the internal potato tissue, netting of tuber skins is undesirable and can affect premiums paid to producers due to the poor physical appearance of the potatoes and their likely rejection by buyers.

**Figure 7** Netting

Photo: British Potato Council

The results of the trial analysis for netting are presented in Tables 21–25.

**Table 21** Mean netting expressed as percentage of tuber surface area of a sample of 50 tubers

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean netting per tuber |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 10.89 | 11.02 | 8.13 | 12.63 | **10.66** |
| 3 t/ha Recycled gypsum | 10.91 | 14.14 | 9.96 | 17.46 | **13.12** |
| 6 t/ha Recycled gypsum | 10.51 | 13.93 | 18.32 | 16.61 | **14.84** |
| 3 t/ha Agricultural gypsum | 14.21 | 10.17 | 13.89 | 11.05 | **12.33** |
| 6 t/ha Agricultural gypsum | 11.79 | 9.15 | 12.31 | 16.71 | **12.49** |
| **Mean netting per tuber** | **11.66** | **11.68** | **12.52** | **14.89** | Grand mean = **12.69** |

**Table 22** Mean netting analysed as percentage of tuber surface area of a sample of 50 tubers with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 0.109 | 0.111 | 0.082 | 0.127 | **0.107** |
| 3 t/ha Recycled gypsum | 0.109 | 0.142 | 0.100 | 0.176 | **0.132** |
| 6 t/ha Recycled gypsum | 0.105 | 0.140 | 0.185 | 0.168 | **0.149** |
| 3 t/ha Agricultural gypsum | 0.143 | 0.102 | 0.139 | 0.121 | **0.126** |
| 6 t/ha Agricultural gypsum | 0.118 | 0.092 | 0.124 | 0.168 | **0.126** |
| **Mean** | **0.117** | **0.117** | **0.126** | **0.152** | Grand mean = **0.128** |

- Soil treatment ($P$)= 0.408
- Nitrogen rate applied ($P$)= 0.229
- Soil treatment × nitrogen rate ($P$)= 0.685

No significant differences in mean netted tuber surface area were observed as a result of any of the soil or nitrogen treatments applied during the trial.

**Table 23** Mean netting severity expressed as percentage of tuber surface area on tubers where netting occurs

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean netting severity per netted tuber |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 17.19 | 16.28 | 19.43 | 21.86 | **18.69** |
| 3 t/ha Recycled gypsum | 17.30 | 20.94 | 19.75 | 28.65 | **21.66** |
| 6 t/ha Recycled gypsum | 18.38 | 19.99 | 26.30 | 27.59 | **23.06** |
| 3 t/ha Agricultural gypsum | 20.72 | 17.35 | 19.05 | 18.95 | **19.02** |
| 6 t/ha Agricultural gypsum | 17.63 | 16.32 | 18.30 | 30.58 | **20.71** |
| **Mean netting severity per netted tuber** | **18.24** | **18.18** | **20.57** | **25.33** | Grand mean = **20.63** |

**Table 24** Mean netting severity analysed as percentage of tuber surface area on tubers where netting occurs, with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 0.173 | 0.164 | 0.196 | 0.221 | **0.188** |
| 3 t/ha Recycled gypsum | 0.174 | 0.211 | 0.199 | 0.291 | **0.219** |
| 6 t/ha Recycled gypsum | 0.185 | 0.201 | 0.267 | 0.282 | **0.234** |
| 3 t/ha Agricultural gypsum | 0.209 | 0.175 | 0.192 | 0.192 | **0.192** |
| 6 t/ha Agricultural gypsum | 0.177 | 0.164 | 0.185 | 0.318 | **0.211** |
| **Mean** | **0.184** | **0.183** | **0.208** | **0.206** | Grand mean = **0.209** |

- Soil treatment (*P*)= 0.600
- Nitrogen rate applied (*P*)= 0.034 Least significant difference (LSD 5%) = 0.0583
- Soil treatment × nitrogen rate (*P*)= 0.897

No significant differences in netting severity were observed with any of the initial soil treatments applied during the trial.

Significant differences in netting severity were observed as a result of differences in total inorganic nitrogen fertiliser applied during the trial, with increased nitrogen rates leading to increased netted tuber surface area.

**Table 25** Netting incidence (expressed as number of netted tubers per 50 tubers)

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean netting incidence per 50 tubers |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 29.67 | 33.33 | 22.00 | 29.00 | **28.50** |
| 3 t/ha Recycled gypsum | 31.50 | 33.49 | 24.67 | 30.67 | **30.08** |
| 6 t/ha Recycled gypsum | 28.33 | 35.00 | 34.00 | 29.33 | **31.67** |
| 3 t/ha Agricultural gypsum | 33.67 | 28.33 | 36.49 | 28.67 | **31.79** |
| 6 t/ha Agricultural gypsum | 34.00 | 27.00 | 31.67 | 30.33 | **30.75** |
| **Mean netting incidence per 50 tubers** | **31.43** | **31.43** | **29.76** | **29.60** | Grand mean = **30.56** |

- Soil treatment (*P*)= 0.620
- Nitrogen rate applied (*P*)= 0.704
- Soil treatment × nitrogen rate (*P*)= 0.154

No significant differences in mean number of tubers showing some degree of netting were observed as a result of any soil or nitrogen treatment applied during the trial.

### *3.2.3 Growth cracks*

A growth crack is the occurrence of deep cracks in surface of tubers (Figure 8) caused through inconsistencies in soil moisture (i.e. periods of drought followed by periods of abundant moisture) which cause tuber growth rates to fluctuate.

When a period of drought is followed by a period of rapid soil wetting, the potato plants quickly take on large volumes of water and growth of tuber tissue becomes quite rapid. If a drought period has previously slowed tuber development and skins become dry, slow growing and inelastic tubers can be prone to splitting as the internal tuber tissues develop too quickly for their skins and pressure builds up before bursting, resulting in growth cracks.

Although not affecting the quality of the internal potato tissue, cracking and deformation are undesirable to consumers.

**Figure 8** Growth cracks

Photo: British Potato Council

The results of the trial analysis for growth cracks are presented in Tables 26-29.

**Table 26** Growth cracks (number of cracks) evident on 50 tubers

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean growth cracks per 50 tubers |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 11.00 | 8.00 | 1.33 | 2.67 | **5.75** |
| 3 t/ha Recycled gypsum | 2.50 | 0.50 | 0.67 | 1.00 | **1.17** |
| 6 t/ha Recycled gypsum | 1.67 | 0.33 | 0.00 | 1.67 | **0.92** |
| 3 t/ha Agricultural gypsum | 5.67 | 4.00 | 0.50 | 0.67 | **2.71** |
| 6 t/ha Agricultural gypsum | 2.00 | 2.67 | 0.33 | 0.67 | **1.42** |
| **Mean growth cracks per 50 tubers** | **4.57** | **3.10** | **0.57** | **1.33** | Grand mean = **2.39** |

- Soil treatment ($P$)< 0.001 Least significant difference (LSD 5%) = 1.667
- Nitrogen rate applied ($P$)< 0.001 Least significant difference (LSD 5%) = 1.500
- Soil treatment × nitrogen rate ($P$)= 0.016 Least significant difference (LSD 5%) = 3.355

The numbers of growth cracks evident was significantly higher where gypsum soil treatments had not been applied.

Agricultural gypsum applied at 3 t/ha achieved a significant reduction in growth cracks compared with untreated soil.

Recycled gypsum applied at both 3 t/ha and 6 t/ha and agricultural gypsum applied at 6 t/ha achieved statistically similar results. These showed a significant reduction in growth cracks compared with the untreated soil and the application of agricultural gypsum at 3 t/ha.

**Table 27** Growth crack incidence (number of tubers per 50 tubers exhibiting at least one crack)

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean growth crack incidence |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 8.67 | 5.33 | 1.33 | 1.67 | **4.25** |
| 3 t/ha Recycled gypsum | 2.00 | 0.50 | 0.67 | 1.00 | **1.04** |
| 6 t/ha Recycled gypsum | 1.33 | 0.33 | 0.00 | 1.33 | **0.75** |
| 3 t/ha Agricultural gypsum | 5.33 | 1.67 | 0.50 | 0.33 | **1.96** |
| 6 t/ha Agricultural gypsum | 1.67 | 1.33 | 0.33 | 0.67 | **1.00** |
| **Mean growth crack incidence** | **3.80** | **1.83** | **0.57** | **1.00** | Grand mean = **1.80** |

- Soil treatment (*P*)< 0.001 Least significant difference (LSD 5%) = 1.148
- Nitrogen rate applied (*P*)< 0.001 Least significant difference (LSD 5%) = 1.027
- Soil treatment × nitrogen rate (*P*)= 0.003 Least significant difference (LSD 5%) = 2.296

The numbers of growth cracks evident was significantly higher where gypsum had not been applied to the soil.

Agricultural gypsum applied at 3 t/ha achieved a significant reduction in growth cracks compared with untreated soil.

Recycled gypsum applied at both 3 t/ha and 6 t/ha and agricultural gypsum applied at 6 t/ha achieved statistically similar results. These showed a significant reduction in growth cracks compared with the untreated soil and the treatment of agricultural gypsum at 3 t/ha.

**Table 28** Growth crack length (where cracks occur) recorded as percentage of tuber length

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean growth crack length (% tuber) |
|---|---|---|---|---|---|
| | **126** | **180** | **240** | **300** | |
| Untreated control | 59.2 | 48.5 | 33.5 | 52.4 | **48.4** |
| 3 t/ha Recycled gypsum | 37.1 | 42.5 | 7.5 | 11.1 | **24.5** |
| 6 t/ha Recycled gypsum | 26.1 | 25.0 | 0.0 | 19.2 | **17.6** |
| 3 t/ha Agricultural gypsum | 32.3 | 38.3 | 2.6 | 10.0 | **20.8** |
| 6 t/ha Agricultural gypsum | 42.5 | 33.7 | 1.7 | 26.7 | **26.1** |
| **Mean growth crack length (% tuber)** | **39.4** | **37.6** | **9.0** | **23.9** | Grand mean = **27.5** |

**Table 29** Growth crack length (where cracks occur) analysed as percentage of tuber length with arcsine transformation

| Soil treatment | Total inorganic nitrogen rate applied (kgN/ha) | | | | Mean |
|---|---|---|---|---|---|
| | 126 | 180 | 240 | 300 | |
| Untreated control | 0.642 | 0.510 | 0.355 | 0.370 | **0.469** |
| 3 t/ha Recycled gypsum | 0.382 | 0.508 | 0.076 | 0.113 | **0.270** |
| 6 t/ha Recycled gypsum | 0.270 | 0.283 | 0.000 | 0.198 | **0.188** |
| 3 t/ha Agricultural gypsum | 0.334 | 0.410 | 0.026 | 0.102 | **0.218** |
| 6 t/ha Agricultural gypsum | 0.463 | 0.352 | 0.017 | 0.299 | **0.283** |
| **Mean** | **0.418** | **0.412** | **0.095** | **0.217** | Grand mean = **0.285** |

- Soil treatment ($P$)= 0.092
- Nitrogen rate applied ($P$)= 0.003 Least significant difference (LSD 5%) = 0.2136
- Soil treatment × nitrogen rate ($P$)= 0.990

The length of growth cracks appears to have been shorter where any gypsum had been applied to the soil, although the analysis of variance does not show this to be statistically significant, with a probability ($P$) value of over 9%.

A significant reduction in growth crack length was achieved at the farm standard nitrogen rate (240 kgN/ha total dose) compared with other nitrogen rates applied during the trial; the 300 kgN/ha total dose resulted in significantly longer cracks than the farm standard rate although it still resulted in significantly shorter cracks than those with dose rates below the farm standard rate.

### *3.2.4 Bloom*

Skin finish is heavily scrutinised and is a common cause of rejection of potatoes by packers and retailers. A good 'bloom' is achieved by a potato with a clean, smooth unblemished and radiant appearance. It is an important factor in securing quality markets and premium market prices for the grower.

Specific assessments of tuber bloom did not form part of the scheduled analyses for this trial as it is a very subjective and complex assessment procedure. As such, the other factors were relied on to act as indicators of quality of skin finish. However, observations and comments made by assessors during other post-harvest analysis of tuber characteristics and quality suggest bloom may have been positively affected by the addition of gypsum to the host soil. Figures 9 and 10 illustrate these observations.

**Figure 9** Potatoes (cv. Estima) grown in untreated soil

**Figure 10** Potatoes (cv. Estima) grown in soil treated with recycled gypsum (3 t/ha)

# 4.0 Soil analysis

To test claims that gypsum can have both physical and chemical benefits when added to agricultural soils, the density of the host soil, and a number of chemical properties, were measured. Samples were taken from each of the plots: the untreated soil, and soil treated with agricultural or recycled gypsum.

Soil science is not an exact science and variability is, to an extent, inevitable. Variations and differences can be attributed, for example, to variability within the soil horizons, the underlying geology and drainage. This should be taken into account when interpreting soil analysis results.

## 4.1 Soil bulk density

Soil bulk density is a measurement of the mass of for a given volume of soil, usually expressed as grams per cubic centimetre ($g/cm^3$). An undisturbed sample of fresh soil is dried to remove all moisture and the weight determined to give a dry bulk density.

Very compacted soils (e.g. poorly structured soils or soils subjected to frequent or heavy traffic) may give typical bulk densities of 1.4–1.6 $g/cm^3$, whereas a better structured, friable soil with a good organic matter content has a bulk density of <1.0 $g/cm^3$.

Determining the dry bulk density for each soil treatment enabled an indication of gypsum's ability to decrease soil bulk density, by comparing the results achieved for soil to which gypsum had been applied with those from the untreated soil.

The bulk density measurement results are given in Table 30.

**Table 30** Dry bulk density assessment from trial site

| Soil treatment | Dry bulk density (g/cm$^3$) | | | Mean dry bulk density (g/cm$^3$) |
|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 3 | |
| Untreated control | 1.30 | 1.30 | 1.36 | **1.32** |
| 3 t/ha Recycled gypsum | 1.32 | 1.37 | 1.38 | **1.36** |
| 6 t/ha Recycled gypsum | 1.36 | 1.33 | 1.35 | **1.43** |
| 3 t/ha Agricultural gypsum | 1.35 | 1.47 | 1.25 | **1.36** |
| 6 t/ha Agricultural gypsum | 1.55 | 1.37 | 1.38 | **1.35** |
| | | | | Grand mean = **1.36** |

- Soil treatment (*P*)= 0.417

No significant differences in soil dry bulk density were measured from any of the recycled or agricultural gypsum treatments compared with each other or with the untreated soil. All gypsum treatments and the untreated soils yielded dry bulk densities of 1.3–1.4 g/cm$^3$, which indicated that in all cases the structure is undesirable – meaning soil aggregation is inadequate and the air spaces present in the soil are low.

Many years of cropping carrots year after year has left the soil with minimal organic matter. This, combined with the high sand fraction of this soil, can help to explain the poor aggregation. The minimal clay fraction in the host soil will prevent soil clods forming, while weathering over time following cultivation and tillage operations tends to lead to soils slumping.

## 4.2 Soil nutrients

The results obtained from the final assessment of soil nutrient levels carried out in August 2006 are presented in Table 31.

**Table 31** Final soil nutrient assessment from trial site, August 2006

| Parameter | | Untreated soil | + Recycled gypsum | | + Agricultural gypsum | |
|---|---|---|---|---|---|---|
| | | | 3t/ha | 6t/ha | 3t/ha | 6t/ha |
| pH | | 7.1 | 7.1 | 6.7 | 6.6 | 6.8 |
| Standard soil nutrient availability indices | Phosphate | 3 | 2 | 3 | 3 | 2 |
| | Potassium | 1 | 2- | 2- | 1 | 2- |
| | Magnesium | 2 | 2 | 2 | 2 | 2 |
| CEC (meq/100g) | | 4.9 | 6.4 | 5.2 | 5.1 | 5.7 |
| Cation exchangeable nutrients (%) | Calcium | 79.6 | 85.1 | 74.4 | 77.8 | 84.1 |
| | Magnesium | 4.7 | 3.7 | 4.6 | 4.7 | 4.5 |
| | Potassium | 13.5 | 9.6 | 18.7 | 15.5 | 9.6 |
| | Sodium | 2.2 | 1.6 | 2.4 | 2.0 | 1.7 |
| Available plant soluble nutrients (mg/l) | Calcium | 1045 | 1024 | 1057 | 975 | 1197 |
| | Sulphate | 43 | 106 | 171 | 105 | 313 |
| | Potassium | 115 | 120 | 120 | 117 | 121 |
| | Phosphate | 26 | 25 | 27 | 26 | 24 |
| Total nitrogen in 0–30cm profile (kg/ha) | | 22.2 | 19.5 | 23.4 | 25.6 | 19.6 |

Key: Very low – Low – Adequate – Excessive

### *4.2.1 Soil acidity*

The optimum pH value for a mineral soil in a continuous arable rotation is around 6.5. If soil acidity is too low (towards pH 4) or too high (towards pH 8), then this can be detrimental to the availability of nutrients and minerals for uptake by the growing crop. Some agricultural practices such as the use of inorganic fertilisers, for example, tend to reduce the pH value of a soil (making it more acidic) and some soils benefit from the addition of lime to correct such a trend.

The initial soil audit of the trial site gave a pH value of 7 (Table 3). With no apparent requirement for lime, it is reasonable to find that none of the pH values from the later soil assessments appear to be significantly outside the optimal range for arable topsoil. Although some differences are seen, there is no obvious trend or relationship between the soil treatment and the variation in results. Indeed, it is likely that the random sampling methods employed to collect the soils could bring about such variations.

### *4.2.2 Nutrient availability indices*

Soil nutrient availability indices are commonly used to provide a measure of levels of nutrients present in a soil and available for uptake by a growing crop. Although the target indices can be different for different nutrients and crops, they provide a straightforward means of determining whether additional nutrients will be required to satisfy crop requirements.

Comparison of the target indices for the major plant nutrients with soil test results influence decisions about fertiliser inputs to the soil and crop.

### *4.2.3 Cation exchange capacity (CEC)*

Exchangeable cations (positively charged ions) are bound weakly to soil particles. This bond prevents leaching losses of such ions (nutrients) with movements of soil water, but is not sufficiently strong to prevent uptake of nutrients into plant roots. The CEC of a soil is a measurement of its ability to bind to exchangeable cations and is indicative of the nutrient holding capacity of a soil.

The CEC is influenced by the parent material of a soil as well as its organic matter content. It is likely to increase in line with a high clay fraction and organic matter content in a soil.

A 'normal' CEC for an agricultural soil is between 15 and 40 milliequivalents per 100 g (meq/100g), with readings below 10 meq/100g considered very low. All the CECs measured in all treatments both before the trial was established and again following harvest were in the very low category (Table 31). This reflects the low clay and organic matter content of the host soil. This is not something that gypsum addition would be expected to correct, but reflects more the soil's need for additional organic matter.

### *4.2.4 Exchangeable nutrients*

Despite slight variability in the actual CECs measured in the gypsum-treated soils, the proportions of each of the major plant nutrients were similar between treatments, regardless of gypsum type or rate used (Table 31). This is certainly the case for calcium, the main nutrient supplied by the gypsum. The changes in the proportions of potassium and magnesium can be accounted for by the addition of inorganic nutrients to the seedbed at the time the potato crop was established.

### *4.2.5 Plant available nutrients*

Perhaps the most important measurement of soil nutrient status is that of the soluble nutrients which are functionally available to the plants for uptake and use during periods of growth.

Comparison of the results of the initial soil assessment with those from the untreated soil at the end of the trial shows a marked increase in the level of available calcium (Tables 3 and 31), with levels doubling over the nine month period between December 2005 and August 2006. The available calcium concentration rose from a very low level to a low level, indicating there was still a requirement to increase the available calcium level in the soil above that achieved by time alone.

Perhaps the most interesting result is obtained when comparing the soil analyses at the end of the trial with each other. While available calcium levels increased with time in soil taken from all the treatments, there was no apparent difference between available calcium levels where gypsum had been applied and levels where it had not. Despite the addition of a significant quantity of calcium to the soil in the form of calcium sulphate, the levels of available calcium remained unaffected. This may indicate that it will take slightly longer before the effects of adding gypsum products can be measured in this way.

However, comparison of the sulphate levels measured at the end of the trial clearly shows that the addition of gypsum resulted in significantly higher sulphate concentrations (Table 31).

The results suggest that comparable amounts of sulphate were delivered by both the recycled gypsum and the agricultural gypsum, when applied at the 3 t/ha rate.

The addition of gypsum at the higher rate (6 t/ha) appeared to provide a further increase in plant available sulphate over and above that provided by the lower rate of gypsum (3 t/ha). Where recycled gypsum was used to treat the soil, a stepped increase in available sulphate occurred between the application of 3 t/ha and 6 t/ha which was of a similar magnitude to that seen between untreated soil and 3 t/ha. Although a much larger increase in available sulphate was observed when 6 t/ha agricultural gypsum was applied to the soil, caution should be exercised when drawing conclusions from this result as it seems far removed from the other results and could be considered an anomalous result.

The use of recycled gypsum is therefore a viable alternative for agricultural gypsum when seeking to increase sulphate concentrations in soil.

### 4.3 Gypsum analysis

Table 32 gives the results of the analysis of the recycled and agricultural gypsums supplied and used in the trial. The analysis included potentially toxic elements (PTE) such as arsenic, cadmium, lead and mercury. While the calcium content of each material was very similar, the recycled gypsum had higher sulphur and sulphate fractions.

**Table 32** Potentially toxic element analysis of recycled gypsum and agricultural gypsum used in the trial

| Element | Unit | Recycled gypsum | Agricultural gypsum |
|---|---|---|---|
| Calcium | %w/w | 18.78 | 18.52 |
| Sulphur | %w/w | 20.92 | 16.04 |
| Sulphate | %w/w | 62.8 | 48.1 |
| Arsenic | mg/kg | 0.32 | 1.20 |
| Cadmium | mg/kg | <0.05 | 0.08 |
| Chromium | mg/kg | 0.33 | 3.88 |
| Copper | mg/kg | 1.17 | 1.95 |
| Lead | mg/kg | 0.06 | 4.19 |
| Mercury | mg/kg | <0.05 | 0.11 |
| Molybdenum | mg/kg | 1.2 | 0.4 |
| Nickel | mg/kg | 0.27 | 2.19 |
| Selenium | mg/kg | 0.18 | 1.57 |
| Zinc | mg/kg | 1.12 | 18.5 |

The recycled gypsum used in the trial matched the 'typical' specification for recycled gypsum material for arsenic, cadmium, lead and mercury (Table 2). All measured levels of these elements were below the maximum levels detailed in the material specification.

The analysis also showed that, with the exception of molybdenum, all PTE levels measured in the recycled gypsum material were below those measured in the agricultural gypsum material.

## 5.0 Economic assessment

The costs of using recycled gypsum in arable agriculture are variable and depend on a number of factors including:

- land area to be treated;
- proximity of that land to the supplier or processor of the product; and
- rate of gypsum to be applied.

All these factors will affect the price of each tonne of material used.

At the time the trial was established, recycled gypsum could be procured for £12–14 per tonne ex-works, though some deals were available locally where this price could include delivery and/or spreading. On a small scale this made recycled gypsum appear very competitive as agricultural gypsum supplied in small bags cost £80–90 per tonne. A considerable saving was therefore possible assuming recycled gypsum could be substituted for other types without a significant reduction in performance or end gains. If spreading were in addition to these prices, a contractor's rate may be up to £2.00–2.50 per tonne.

Bulk purchasing of virgin mineral gypsum for agricultural use (i.e. significant quantities of non-bagged product) is likely to reduce the price per tonne. Reports shortly after the establishment of this trial suggested that suppliers were bringing their prices down to compete with the availability of competitive alternatives (e.g. increased availability of recycled gypsum). Thus choices are likely to be made based on local availability and haulage costs rather than product differences.

To give an idea of the 'value' of recycled gypsum in terms of crop quality and premiums, it is necessary to consider the end market in which the crop is sold. Any increase or improvement in skin finish quality will help to guarantee acceptance of a potato crop into the pre-pack market. Pre-pack potatoes are sold directly to consumers as potatoes in the supermarket as opposed to those destined for processing (frozen chips, crisps, ready meals, etc.) before reaching the consumer. As a result, the pre-pack market can be very selective as the modern consumer is demanding increasingly more visually appealing produce. Depending on yields, a grower would look to receive £4800–7500 per hectare for a crop accepted for the pre-pack market. The alternative (i.e. failing to make the pre-pack grade) could result in the crop selling for only around £500 per hectare – if it can be sold at all.

The yield from the rest of the field in which this trial was conducted did sell into the pre-pack market. The field yielded just over 46 t/ha, of which just less than 43 t/ha was of marketable quality (correct size and without significant skin defects). Selling for £110 per tonne, the grower received around £4700 per hectare for his potato crop (ex-farm price).

# 6.0 Conclusions

## 6.1 Recycled gypsum application and crop safety

Gypsum in the form of recycled gypsum can be applied at rate of up to 6 t/ha without compromising the establishment of the potato crop or making it necessary to change current farm practices for seedbed preparation or planting following the spreading operation. The number of plants established in the trial was uniform regardless of soil treatment or gypsum application rates up to at least 6 t/ha.

No phytotoxicity (injury, illness or damage caused to plants by materials such as fertilisers or pesticides) was observed in the potato crop at any time due to the presence of recycled gypsum in the soil.

## 6.2 Potato harvesting and yield

The use of recycled gypsum as a soil conditioner did not demonstrate any advantage in terms of increased yield and, in some cases, resulted in reductions in harvested yield mass and tuber quantity.

There was no effect on tuber soil adhesion on the potato crop grown on the sandy loam soil as measured by the soil tare method. In situations where heavier soils are cropped with root vegetables, it is possible that significant effects might be seen. But as harvesting was carried out reasonably early and in good weather and soil conditions, soil adhesion to the tubers grown in the untreated soil blocks in this trial was negligible.

No advantages or detrimental effects were seen from any of the gypsum soil treatments or different application rates on the proportion of total harvested yield that fell into the marketable yield fraction, whether measured by mass or tuber number.

Although no statistical differences were found and despite the relatively small sample size, there were signs that fewer rotten tubers were collected from plots where applications of recycled gypsum were made prior to crop establishment.

## 6.3 Potato quality and tuber skin finish

Neither the occurrence nor severity of common potato scab or potato skin netting was affected by the use of gypsum (agricultural or recycled) as soil conditioners when growing cv. Estima on sandy loam soil.

The occurrence and severity of growth cracks in potato tuber walls was significantly reduced when gypsum was used as a soil conditioner when growing cv. Estima on sandy loam soil. Recycled gypsum appeared to control the occurrence and severity of growth cracking at least as well as agricultural gypsum and, in some cases, achieved significantly better control.

Observations of skin finish and bloom suggested that gypsum soil treatments can lead to a brighter and more marketable skin appearance. But as no formal assessment of this apparent benefit was made during the trial, further work is required before this claim can be confirmed.

## 6.4 Soil quality

Soil bulk density was not reduced through the use of gypsum at application rates of up to 6 t/ha on sandy loam soil in this trial. However, it is possible that either higher application rates or additional applications at similar rates over a sustained period might begin to lower bulk densities measurably. The high sand fraction combined with low clay and organic matter content of the host soil may limit the extent to which gypsum might make a difference on its own. That is not to say that structural changes and improvements will not have been made and longer term studies might illustrate this better.

Similarly, the soil acidity (pH) remained unchanged where gypsum was used compared with untreated soil. As the host soil was already around pH 7 (i.e. neutral), it was not possible to measure any neutralising effect that gypsum may exert on more acidic or alkaline soils. Continuous use of inorganic fertilisers can lower soil pH values over time, so it is possible that periodic use of gypsum could negate the liming requirement in soils prone to being affected by fertilisers in this way.

The availability of the major plant nutrients, as indicated by the soil nutrient availability indices, appeared to be relatively unaffected when gypsum was used. That is not to say that uptake did not increase as gypsum may have prevented some loss of soluble nutrients through leaching and therefore made more available for use by the crop. But as the crop was subjected to a fertiliser regime to match its predicted nutrient draw (see Section 2.4), it is necessary to consider this soil measurement together with the yield response to determine whether crop uptake and therefore crop growth improved. As detailed above, yield increases with the use of recycled gypsum were not seen in this trial so it cannot be said at this stage that nutrient uptake improved in the first period of cropping after gypsum application.

The cation exchange capacity of the host soil was very low overall. Following the harvest of the potato crop, the CEC was measured in a sample taken from each soil treatment. All treatments gave slightly higher CEC readings than the untreated soil measured at the same time. However, the variability in these readings could not be correlated with the different gypsum products or rate of application. It is possible that these results are due to natural variation of the soil within the trial field. It cannot therefore be concluded that application of gypsum helped to increase the CEC of the sandy loam soil though, if effective changes in CEC take time to occur, further applications over a period of time may show a more certain trend. Where soils are low in silica (clay) and organic matter, additions of compost, for example, could be made together with gypsum as part of a programme to increase the nutrient holding capacity (CEC) of some soils.

The levels of available sulphate rose where gypsum was used, with higher application rates producing larger increases. Although sulphate was applied to the seedbed as part of the compound fertiliser used as a standard treatment by the farm, this was uniform over the entire trial area. It is therefore possible to make comparisons with a good level of confidence.

The results suggest that recycled gypsum contributed to increasing the levels of available sulphate in sandy loam soil. Its performance was the same as agricultural gypsum, certainly at the 3 t/ha rate of application. At the 6 t/ha rate, available sulphate levels in the soil look to have increased proportionally where recycled gypsum was used. Where agricultural gypsum was used, the recorded levels were much higher but this single result should be treated with caution until further replicated measurements can be made.

## 6.5 Potentially toxic elements

In general, the levels of potentially toxic elements and heavy metals present in the samples of recycled gypsum did not exceed those present in the agricultural gypsum. As agricultural gypsum is a naturally occurring material supplied for unrestricted agricultural use, recycled gypsum containing equal or lower levels of such elements could be safely substituted for agricultural gypsum in similar applications.

Molybdenum was the only heavy metal determinand that appeared at higher levels in the recycled gypsum. Although the molybdenum concentration was three times higher in the recycled gypsum than in the agricultural gypsum (1.2 mg/kg compared with 0.4 mg/kg), addition to agricultural soils at this level is not deemed to be a problem or likely to present a potential future problem. Molybdenum may be toxic at significantly excessive levels and could potentially be accumulated in some root crops, but there are no reports of such incidents occurring. Defra and the Environment Agency did not deem it necessary to include specific guidelines in *Potential Contaminants for the Assessment of Land*[1] for maximum levels of molybdenum in soil or those that may be added to soil.

Molybdenum levels in digested biosolids (sewage sludge) at levels 7–8 times higher than those measured in the recycled gypsum would normally be acceptable and permitted by the Environment Agency for application to agricultural land at rates in excess of 20 t/ha biosolids. This equates to 25–30 times the level of molybdenum that would be delivered by an application of recycled gypsum at 6 t/ha or equivalent to that delivered by an application of 165 t/ha recycled gypsum. Therefore, it seems unlikely that the use of recycled gypsum would present any problems by elevating molybdenum concentration in soil to unsafe levels. However, it is good practice to monitor soils through periodic testing and especially where recycled waste products are being applied to land for food production.

### 6.6 Economic impacts

As a result of the trial, the host farmer has stated he is convinced of the benefits of gypsum use through its effects on the soil, the crop and skin finish quality. He therefore intends to continue its use on his fields where required. Recent enquiries suggest that recycled gypsum could be procured for £16 per tonne (delivered and spread) from a reasonably local processor. If he is to proceed with such applications in the coming year and assuming a rate of 3 t/ha is used, the cost is likely to be £59 per hectare treated. This includes the Environment Agency registration fee for the waste management licence exemption (Paragraph 7A), which is currently equivalent to a minimum £11 per hectare (see Section 7.1). Additional costs associated with registering the activity include soil testing and administration time.

All this adds up to an investment of around 1.5% of the market value of the potato crop removed and sold in a single season. The effects of gypsum treatment are likely to be seen in subsequent crops and pay back its direct costs over a number of years, depending on rate used and frequency of re-application. Even if the use of gypsum has only short-lived effects, such an expense is likely to be justifiable if a consistent or higher quality crop is achieved through general soil conditioning, potentially leading to higher premiums for the grower.

This would also help crop growth directly as well as easing pressure on equipment, potentially shortening the turnaround time between crops through widening weather windows during which it is possible to travel on the land with machines for establishment and spraying.

## 7.0 Potential issues and further research opportunities

A number of potential issues arose during the project that may need to be addressed to facilitate more widespread uptake of the use of recycled gypsum in agriculture. Those areas where there is room for improvement or potential barriers exist are highlighted below.

### 7.1 Permit to use

Under current legislation, anyone wishing to apply recycled gypsum to agricultural land must register the activity as exempt from the Waste Management Licensing Regulations 1994 (as amended). In England and Wales this is undertaken through obtaining from the Environment Agency a Paragraph 7A exemption, for which their current[2] charge is £546.00 to register the activity, with no guarantees of permission and no refunds or discounts if permission is not granted. The exemption can be used for up to a maximum of 50ha of land (though this land need not be continuous); a further exemption must be obtained for additional areas of land.

This creates a barrier to increasing the use of recycled gypsum as the extra financial cost is a minimum of £10.92/ha (£546/50ha, in England and Wales) without the cost of the farm manager's time spent completing the forms.

[1] *CLR8, March 2002 (www.environment-agency.gov.uk/commondata/acrobat/clr8_675394.pdf)*

[2] *2007/2008*

A second issue is the potential 35-day waiting period between the regulator receiving an application for an exemption and being obliged to give a decision (i.e. grant or withhold consent). With sufficient planning, this need not be a major issue from the point of farmers deciding to use or not. However, it might cause problems with securing supplies from recyclers and processors. Farmers would not be able to agree a contract to supply before permission was obtained to use recycled gypsum, but would perhaps be reluctant to submit an expensive application without knowing that their needs could be met with an appropriate tonnage of material as soon as consent was given.

**Quality Protocol**

Work is currently underway to overcome the above situation by the development of a Quality Protocol for recycled gypsum.

A Quality Protocol is a document which sets out criteria on how to produce a product from a specific waste type; in this case recycled gypsum from waste plasterboard. The purpose of this is that if the producer (for example, a plasterboard recycler) complies with the criteria the user can use the recovered product without the need for waste regulatory control. Quality Protocols also indicate how the producer can demonstrate compliance, and points to best practice for the use of the recovered product.

The aim of producing Quality Protocols is to provide increased market confidence in the quality of products made from waste and so encourage greater recycling.

The waste protocols project is a joint Environment Agency and WRAP initiative, funded by the Defra BREW programme. It is currently envisaged that a Quality Protocol for recycled gypsum may be published by summer 2008.

## 7.2 Spreading techniques

The most appropriate items of commonly available commercial farm equipment were employed during the trial to spread the gypsum powders. A spreader consisting of a large hopper with a moving floor and spinning discs (Figure 11) is often used to spread similar materials (such as lime) to land.

The main issue arising from the spreading was potential nuisance caused to neighbours from dust drifting during application. During the trial it was noticed that, while the majority was spread successfully to the intended area, both recycled gypsum and the agricultural gypsum were prone to dust drifting on even the lightest of breezes (both being fine, dry powders). This could cause problems where spreading is carried out near a public highway where motorists might suffer reduced visibility.

One potential solution may be to increase the moisture content of the gypsum product to reduce the free dust, although this may increase lumps and caking of the powders during storage.

An alternative may be to grade the recycled gypsum such that the material supplied for agricultural use consists of the larger grades, for example possibly >5–6 mm. This would spread more like solid fertilisers, which are often prilled (small and bead-like in nature). In this case, the fine fraction of recycled gypsum could be separated and returned for alternative uses (perhaps plasterboard manufacture). Another option is to not grind the waste plasterboard as finely in the first place to producer a coarser material. It is likely to be impossible to eliminate dust completely but a significant reduction would be desirable.

A disadvantage of using larger grade gypsum could be that it takes longer for the effect on the soil to occur, as it would need to crumble to a fine size to interact with the soil particles.

A third option could be to combine gypsum powder with another material to act as a carrier. This would increase the volume of product to be spread but, if the carrier also provided some benefit to agricultural land (perhaps organic materials such as compost or manure), it could be treated more like a soil conditioning compound.


**Figure 11** Spreading mechanism of the lime spreader used

## 7.3 Soil types

This trial involved a single crop type on a single soil type in a given growing season. For various reasons (as discussed in this report), the exact benefits of including recycled gypsum in the crop rotation on a commercial arable farm are likely to vary according to a number of factors, not least the make-up of the host soil. Rainfall, temperature and crop type are other factors likely to affect the activity of gypsum when applied to an agricultural soil.

## 7.4 Application rates

This trial looked only at the effect of two different application rates. The 3 t/ha rate was used because it represents the equivalent of 1.2 tons per acre, which anecdotal evidence suggested was a commonly used rate when natural mineral gypsum was used in agriculture.

The agricultural gypsum supplier's data sheet suggests an application rate of 500 g/m$^2$, which is equivalent to 5 t/ha. The rate of 6 t/ha was used in the trial as a comparison to indicate whether the effects of gypsum use would increase with increasing application rates.

More work is needed to investigate the effects of different application rates perhaps to establish:

- maximum or minimum useful rates for achieving different end gains; or
- optimum rates of use according to soil type or cropping.

## 8.0 List of abbreviations

| | |
|---|---|
| CEC | cation exchange capacity |
| $g/cm^3$ | grams per cubic centimetre |
| ha | hectare |
| kg/ha | kilograms per hectare |
| kgN/ha | kilograms of nitrogen per hectare |
| meq/100g | milliequivalent [one-thousandth equivalent] per 100g soil |
| N | nitrogen |
| t | metric tonnes |
| t/ha | tonnes per hectare |

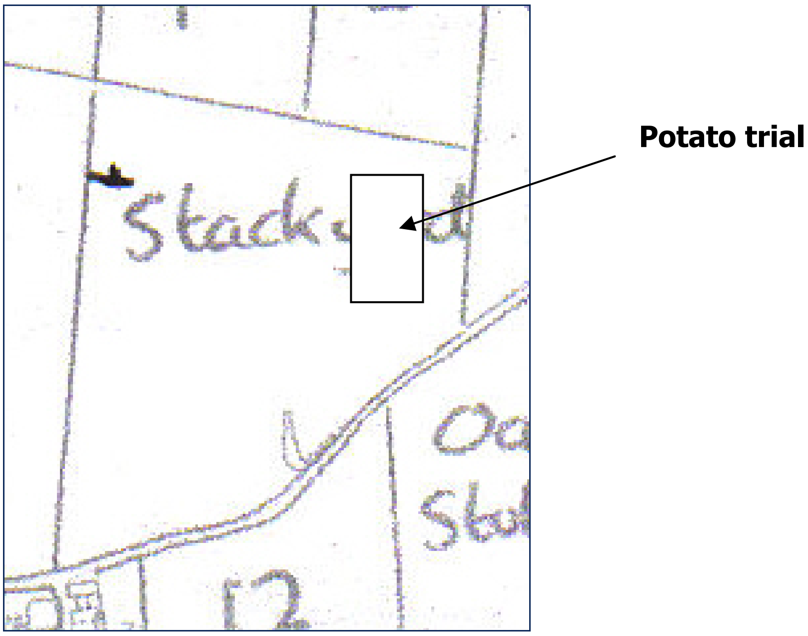
# Appendix A Trial field location and trial position within field

The farm map (Figure A1) shows the trial field 'Stackyard T' (ringed) and its location in relation to the nearest village of Tunstall, Suffolk.

**Figure A1** Farm map showing trial field (ringed)


The trial was located in the west section of the field (Figure A3). The trial area was approximately 48 metres wide and 72 metres long.

**Figure A3** Location of trial in field



**Written by:** Paul Cartwright, Velcourt (R&D) Ltd

Published by
**Waste & Resources Action Programme**
The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH
Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk
Helpline freephone
0808 100 2040
www.wrap.org.uk