FINAL PROJECT REPORT

ENTRUST PROJECT 675382.006
IS STRUVITE A VALUABLE PHOSPHATE SOURCE FOR AGRICULTURE?

Background

The UK horticultural and agricultural industries rely on large inputs of phosphate fertilisers to maintain crop yields and quality. However, the use of manufactured phosphate fertilisers is unsustainable. World-wide, over 33 million metric tonnes of manufactured phosphates are consumed annually (Food and Agriculture Organization, 2005). This requires over 130 million metric tonnes of rock phosphate. Furthermore, the manufacture of phosphate fertilisers depletes finite resources. Rock phosphate reserves will exhaust over the coming decades (Runge-Metzger, 1995) and approximately 50% of mined sulphur is used as sulphuric acid by the phosphate fertiliser industry (Sauchelli, 1965). Thus, the use of alternatives to chemical P-fertilisers is an immediate priority. **The aim of this project was to investigate struvite as an alternative to chemical P fertilisers.**

Struvite $[(NH_4)Mg(PO_4)\cdot6(H_2O)]$ is a natural waste product. Preliminary observations indicated that struvite may be a good alternative phosphate (nitrogen and magnesium) fertiliser for crop production (Johnston and Richards, 2003). Struvite precipitates out of sewerage sludge and animal waste, and can build up in sewers and in sewerage treatment works. This causes operational difficulties and decreased efficiency (Jaffer *et al*., 2002). The physical removal and disposal to landfill of crystallised struvite is expensive and unsustainable. Therefore, the use of struvite as an alternative fertiliser is an attractive proposition. In addition, struvite can also be recovered from animal wastes, principally pig slurry but also chicken litter (Battistoni *et al*., 1997; Greaves *et al*., 1999). Because conventional disposal of untreated animal wastes increases the risk of pollution, and because such practices are becoming legally restricted, alternative disposal routes for struvite must be considered. Since it may be economical to recover struvite from both industrial and agricultural sources for use as an alternative P fertiliser, this project investigated the potential of using struvite as a P fertiliser for potato production.

Results

Since inefficient P fertilisation is a particular problem for the potato crop, which utilises little of the P fertiliser applied (RB209: Defra Fertiliser Recommendations), the use of struvite as an alternative to chemical P fertilisers was assessed using potatoes. Three batches of chemically synthesised struvite (Budit 370) were obtained from Budenheim Ibérica (Spain). Synthesised struvite was used due to the large quantities required for a field trial. The availability of N from synthesised struvite may differ from recovered struvite, where it may be present in more organic forms, which will require mineralisation before becoming available to the crop. The synthetic struvite was a very light, fine white powder. Chemical analysis of the struvite showed it to be a 40:60 mixture of $NH_4MgPO_4\cdot6H_2O$: $NH_4MgPO_4\cdot H_2O$, with a P content of 13.8%.

Two sets of P-fertiliser gradients were established on a field site of low P-status at Wharf Ground, Warwick-HRI, Wellesbourne (latitude 52°12′31″ N, longitude 01°36′38″ W, 48.8 m above sea level). This soil is of the Wick series in the English classification (Whitfield, 1973). The field had not received P and K fertilisers for about 20 years but was regularly cropped during that period. One set of gradients was established using triple super-phosphate (TSP) and the other was established using struvite as the source of P. Each set of gradients consisted of three independent gradients, each containing eight plots. The soil P index of each plot was then adjusted by the addition of either TSP or struvite, to give a range of Defra soil P indices from three to nine. Soil samples from each plot were analysed before and after establishment of the gradients to ensure the correct amount of P was applied.

Seed potatoes (*Solanum tuberosum* var. Kennebec; Higgins Agriculture Ltd., UK) were planted on 31 March 2004. Potatoes were subsequently cultivated according to best agronomic practice. Seed tubers were sampled at pre-planting, shoots, roots and tubers were sampled at tuber initiation and tubers were sampled at commercial maturity. The responses to increasing P-fertilisation of plant yield and tissue mineral contents were determined.

Seed tubers prior to planting had a mean dry weight of 29.03 g plant^{-1} (±1.99 SEM). Seed tubers were also analysed for mineral nutrient concentrations to provide background data. At tuber initiation, indicated by flowering, three plants were harvested from each plot and separated into shoots, roots, tubers and seed tubers. Fresh and dry weights were determined for the bulked samples from each plot, prior to analysis for mineral nutrient concentration (Figure 1). Data were analysed using a two-way ANOVA (GenStat 7th Ed., VSN International Ltd, UK) to determine the effects of the source of P (treatment) and the level at which P was supplied (level) on the potato plants at tuber initiation. There was a significant effect of treatment on root and tuber dry weight ($P<0.01$) and a significant effect of P level on root and shoot dry weights ($P<0.05$), with tissue dry weights from plants supplied with P in the form of struvite being greater than tissue dry weights from plants supplied with P in the form of TSP for the majority of comparisons. The level at which P was supplied had a significant effect ($P<0.05$) on all shoot mineral concentrations at tuber initiation, except for Mn and the source of P had a significant effect on shoot N, P, K, Mg, Cu, Fe, and Mn concentrations (Table 1). With the exception of K, shoot mineral concentrations were significantly higher for plants supplied with P in the form of struvite compared to plants supplied with P in the form of TSP, for the majority of comparisons.

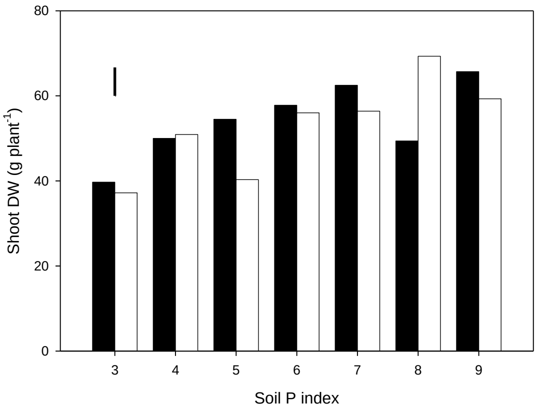

Figure 1. Mean shoot dry weights of potato (*Solanum tuberosum* var. Kennebec) plants at tuber initiation. Potatoes were grown at a range of Defra soil P indices from three to nine, where P was supplied as struvite (filled bars) or triple super phosphate (open bars). Error bar represents mean experiment SED with n=6 for P index 3 and n=3 for all other P indices.

Table 1. *Summary of shoot mineral concentrations for potato plants harvested at tuber initiation*

	Means								
Soil P index	3		6		9			Significance	
Treatment	Struvite	TSP	Struvite	TSP	Struvite	TSP	SED	Treatment	Level
Macro-nutrients									
mg N g^{-1} DW	37.08	37.80	52.14	41.87	59.66	42.66	1.44	<0.001	<0.001
mg P g^{-1} DW	2.15	1.40	5.45	3.36	7.24	4.83	0.28	<0.001	<0.001
mg K g^{-1} DW	28.38	44.62	19.73	34.24	21.73	30.62	2.39	<0.001	<0.001
mg Mg g^{-1} DW	8.08	7.01	11.89	7.90	12.42	8.81	0.50	<0.001	<0.001
mg Ca g^{-1} DW	25.85	19.66	21.12	26.30	17.82	24.65	1.68	0.595	0.042
Micro-nutrients									
µg B g^{-1} DW	18.54	36.18	15.75	26.77	15.89	22.49	7.16	0.126	0.017
µg Cu g^{-1} DW	10.25	7.98	10.87	8.29	14.53	9.01	1.23	0.009	<0.001
µg Fe g^{-1} DW	1169	752	1487	744	861	808	211	0.050	0.021
µg Mn g^{-1} DW	87.00	170.70	82.40	115.70	121.30	73.10	22.50	0.035	0.060
µg Zn g^{-1} DW	43.68	39.76	31.59	30.55	39.14	31.5	3.15	0.320	<0.001

Potato (*Solanum tuberosum* var. Kennebec) plants were grown at a range of Defra soil P indices from three to nine, where P was supplied as struvite or triple super phosphate (TSP). Shoots were harvested, dried and analysed for mineral content using ICP-OES and expressed on a dry weight (DW) basis. n=6 for P index 3 and n=3 for P indices 6 and 9. A two-way ANOVA (GenStat 7th Ed., VSN International Ltd., UK) was used to determine the effects of the source of P (treatment) and the level at which P was supplied (level).

The mineral concentrations of potato roots and tubers were also determined at tuber initiation. There was a significant (*P*<0.05) effect of P level on root and tuber N, P, Mg, Cu, and Zn concentrations, with tissues from plants supplied P in the form of struvite having higher mineral concentrations in the majority of comparisons. The effect of treatment was greatest for P and Mg concentrations, with root and tuber tissues from plants supplied with P in the form of struvite having significantly higher mineral nutrient concentrations than plants supplied with P in the form of TSP. As with shoots, root and tuber K concentrations were significantly (*P*<0.05) higher in plants supplied with P in the form of TSP compared to plants supplied with P in the form of struvite.

The potato crop was subsequently grown to maturity to enable commercial yield to be determined (Figure 2). Potatoes were harvested and graded by size into tubers that were smaller than ware grade (< 40 mm), ware grade (40 – 65 mm) and tubers that were larger than ware grade (> 65 mm).

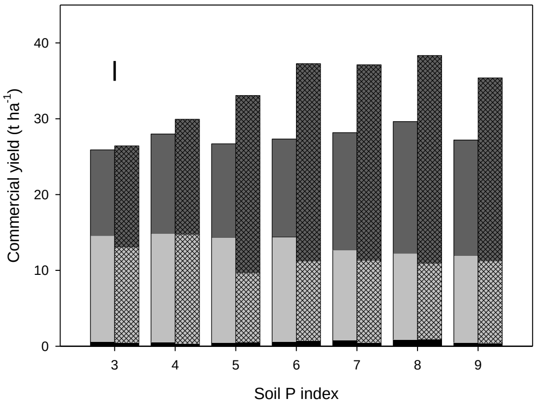

Figure 2. Commercial yields for potato (*Solanum tuberosum* var. Kennebec) crop at maturity. Potatoes were grown at a range of Defra soil P indices from three to nine, where P was supplied as struvite (plain bars) or triple super phosphate (cross-hatched bars). Potatoes were harvested and graded by size into tubers that were smaller than ware grade (black), ware grade (40 – 65 mm; light grey) and tubers that were larger than ware grade (dark grey). Error bar represents mean experiment SED with n=6 for P index 3 and n=3 for all other P indices.

The form and level at which P was supplied had a significant (*P*<0.03) effect on commercial yield, with plots supplied with TSP having significantly higher yields than plots supplied with struvite at all soil P indices. The effect of P level on commercial yield for plots supplied with struvite was not significant. At tuber initiation, plants supplied with P in the form of struvite had higher yields than plants supplied with P in the form of TSP. The increased yield observed for plots supplied with P in the form of TSP compared to plots supplied with P in the form of struvite may be attributed to a potential potassium deficiency observed in potatoes grown on plots supplied with struvite. This is supported by the significantly higher tissue K concentrations observed at tuber initiation and maturity in plants supplied with TSP compared to those supplied with struvite. This could be attributed to the use of the TSP plots in the previous season for growing a short term experimental brassica crop. Consequently, these plots had received K fertiliser in the previous season, whereas, the plots treated with struvite had not. However, it should be noted that all plots received 600 kg ha^{-1} of sulphate of potash (equivalent to 300 kg ha^{-1} K_2O for soil K index 2 according to Defra RB209 recommendations). This issue should be resolved following analysis of data from a second year of field trials in 2005.

Sub-samples of tubers for each plot were subsequently analysed for mineral nutrient concentrations (Table 2). There was a significant effect of treatment on tuber, N, P, K and Mg concentrations with tuber from plots treated with struvite having higher N and P concentrations and tubers from plots treated with TSP having higher K and Mg concentrations. There was also a significant effect of P level on N and P with tuber mineral concentration increasing with P level (Table 2). A significant effect of treatment was observed for tuber B, Fe and Mn concentrations.

Table 2. *Summary of tuber mineral concentrations for potato plants harvested at maturity*

	Means								
Soil P index	3		6		9			Significance	
Treatment	Struvite	TSP	Struvite	TSP	Struvite	TSP	SED	Treatment	Level
Macro-nutrients									
mg N g^{-1} DW	13.52	13.20	16.00	12.99	19.44	14.45	1.04	0.011	<0.001
mg P g^{-1} DW	2.23	1.83	3.69	3.14	4.72	4.25	0.26	0.031	<0.001
mg K g^{-1} DW	13.10	18.13	13.23	18.21	14.97	17.80	1.16	0.003	0.633
mg Mg g^{-1} DW	1.24	1.67	1.22	1.55	1.71	1.62	0.11	0.012	0.026
mg Ca g^{-1} DW	0.80	0.83	0.63	0.83	0.72	0.78	0.07	0.140	0.084
Micro-nutrients									
µg B g^{-1} DW	16.37	10.65	12.41	10.23	14.50	10.60	2.11	0.046	0.559
µg Cu g^{-1} DW	13.05	13.39	14.92	11.35	15.14	12.55	1.96	0.243	0.619
µg Fe g^{-1} DW	888.00	1185.00	642.00	947.00	899.00	781.00	145.50	0.022	0.052
µg Mn g^{-1} DW	28.67	41.75	24.00	32.08	31.61	29.11	3.34	0.010	0.002
µg Zn g^{-1} DW	23.05	23.16	28.76	23.74	26.51	19.44	3.35	0.214	0.271

Potato (*Solanum tuberosum* var. Kennebec) plants were grown at a range of Defra soil P indices from three to nine, where P was supplied as struvite or triple super phosphate (TSP). Tubers were harvested, dried and analysed for mineral content using ICP-OES and expressed on a dry weight (DW) basis. n=6 for P index 3 and n=3 for P indices 6 and 9. A two-way ANOVA (GenStat 7th Ed., VSN International Ltd., UK) was used to determine the effects of the source of P (treatment) and the level at which P was supplied (level).

Conclusions

The suitability of struvite as an alternative to chemical P fertilisers was investigated in the potato crop under field conditions. Analysis of data from plants harvested at tuber initiation revealed that plants supplied with P in the form of struvite had significantly higher tissue dry weights and tissue N, P and Mg concentrations compared to plants supplied with P in the form of TSP (Figure 1; Table 1). However, at commercial maturity, the final harvest showed that plots supplied with P in the form of TSP had significantly higher commercial yields compared to plots supplied with P in the form of struvite (Figure 2). The depressed yield of plots supplied with P in the form of struvite might be attributed to a potential potassium deficiency observed in plants grown on these plots. Further field trials, supported by Defra, are currently underway to address this issue. The potential for struvite as an alternative to chemical P fertilisers is still realistic based on data at tuber imitation. Further research must address whether any potassium deficiency might be remedied.

Project Outputs

- This project has enabled HRI to secure a further £547,000 funding from Defra to investigate "sustainable phosphorus fertilisation of potatoes" (HH3504SPO) over four years, from April 2004.

- Details of this project were presented on a poster at an international conference on ‘Struvite: Its role in phosphorus recovery and use’ at Cranfield University (17-18 June 2004). This contribution was also featured in the Centre Européen d’Etudes sur les Polyphosphates (CEEP) Scope Newsletter 57, available from http://www.ceep-phosphates.org/

- Aspects of this work have also been discussed at three international conferences: (i) Hammond JP, White PJ, Broadley MR, Bennett MJ (2004). P4.13 Taking the P out of plants - Understanding plant responses to P deficiency. In: Abstracts of the Annual Main Meeting of the Society for Experimental Biology, March 2004. *Comparative Biochemistry and Physiology,* **Part A 137**, S195. (ii) Hammond JP, White PJ, Broadley MR (2004). Diagnosing phosphorus deficiency in plants. In: *Aspects of Applied Biology 72, Advances in applied biology: providing new opportunities for consumers and producers in the 21st century*. Association of Applied

Biologists, Wellesbourne, UK, pp. 89-98. (iii) White PJ, Broadley MR, Hammond JP, Thompson AJ (2005). Optimising the potato root system for phosphorus and water acquisition in low-input growing systems. In: *Aspects of Applied Biology 73, Roots and the soil environment*. Association of Applied Biologists, Wellesbourne, UK.

- Our work on P-fertilisation has featured in three general articles: (i) White P, Broadley M, Burns I, Greenwood D, Hammond J, Meacham M, Rahn C, Stellacci A-M (2003) Matching fertilizers to crop varieties. Fruit & Veg Tech 3, 18-20. (ii) White PJ (2003) Efficient use of nutrients. Plant it! 4, 6. Defra: UK. (iii) White PJ, Broadley MR, Burns IG, Greenwood DJ, Hammond JP, Meacham MC, Rahn C, Stellacci A-M (2004). Making the most of phosphate fertilisers. The Grower, 24th June 2004, pp. 14-15.

- Our field trials were displayed at the Midland Regional Grower Show at HRI-Wellesbourne (June, 2003) and our work on "Finding fertiliser-efficient plants" was included in the BBSRC stand on "Sustainable Agriculture" at the Royal Show, Stoneleigh (July, 2003).

- Aspects of this project were presented in lecture courses at the Universities of Coventry (P.J. White), Nottingham (M.R. Broadley), Bratislava (P.J.White) and in a lecture given by P.J. White on "Plants that make the most of phosphate" at the University of Minia (Egypt) sponsored by The British Council.

References

Battistoni P, Fava G, Pavan P, Musacco A, Cecchi F (1997). Phosphate removal in anaerobic liquors by struvite crystallization without addition of chemicals: preliminary results. *Water Research*, **31**, 2925-2929.

Food and Agriculture Organization (FAO) of the United Nations (2005). (http://apps.fao.org/).

Greaves J, Hobbs P, Chadwick D, Haygarth P (1999). Prospects for the recovery of phosphorus from animal manures: A review. *Environmental Technology*, **20**, 697-708.

Jaffer Y, Clark TA, Pearce P, Parsons SA (2002). Potential phosphorus recovery by struvite formation. *Water Research*, **36**, 1834-1842.

Johnston AE, Richards IR (2003). Effectiveness of different precipitated phosphates as phosphorus sources for plants. *Soil Use and Management*, **19**, 45-49.

Runge-Metzger A (1995). Closing the cycle: Obstacles to efficient P management for improved global security. In: *Phosphorus in the Global Environment: Transfers, Cycles and Management,* pp. 27-42 (Ed. H. Tiessen) John Wiley and Sons, New York.

Sauchelli V (1965). *Phosphates in Agriculture*. Chapman and Hall, London.

Whitfield WAD (1973). The soils of the National Vegetable Research Station, Wellesbourne. Report of the National Vegetable Research Station for 1973, pp.21-30.

John P Hammond & Philip J White
Warwick HRI
29th March 2005