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Improving supply and phosphorus use efficiency in organic farming systems

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Summary

Phosphorus (P) is an essential plant nutrient that needs to be managed carefully in organic systems so that crop yield and quality remain sustainable without contributing to environmental damage, particularly that associated with eutrophication. Under organic regulations, minimally processed rock phosphate (PR) can be used to amend low P fertility soils, although the solubility is extremely low at optimum soil pH for most crop growth (pH 6.5). This paper describes a project (PLINK) which aims to develop methods of improving P efficiency on organic farms, although the same approaches may also be applicable on conventional and low-input farms. The methodologies that the project is developing include the fermentation and composting of crop waste material with PR in order to solubilise P and make it more available to the crop. Some initial results are described here. In addition, the project will investigate the alteration of the rotation to include crops or varieties with high P uptake efficiency, or roots that possess acidifying properties which improve P availability for following crops.

Key words: Rock phosphate, solubility, organic farming, fermentation, compost

Introduction

Initiatives from the UK government in the form of UK Organic Action Plans (OAPs) from both Defra (Department of Environment, Food and Rural Affairs) and SEERAD (Scottish Executive Environment and Rural Affairs Department) have been developed in order to try to increase the proportion of organic food consumed in the UK. The intention is that 70% of the organic food consumed in the UK will be produced by UK farmers and growers, and for this goal to be realised, a considerable increase in the area of agricultural land dedicated to organic production would be required. Phosphorus (P), one of the main plant nutrients required for healthy crop growth, will need to be managed extremely carefully in these organic production systems or else crop health, yield and quality will be negatively affected, with the environment also under increased threat of damage as a result of poor stewardship. Organic rules prohibit the use of soluble P fertilisers such as triple super phosphate, and P inputs are based around the addition of sparingly soluble rock phosphate (PR) which has been minimally processed. The solubility of PR is particularly poor at pH 6.5, the optimum for growth of a wide range of arable and horticultural crops. One way to help optimise P use in organic systems is to utilise crops or varieties with high P uptake efficiency into the rotation. Other approaches include the fermentation or composting of crop residues and waste materials with the PR in order to make P more available to the crops when they need it. These approaches have not been investigated in depth in field conditions, particularly in the UK. For improvements in the best management practices to improve P use and efficiency on organic farms, more detailed studies of the factors involved need to be undertaken. This paper describes the approaches taken and some initial laboratory results from a Defra LINK project (PLINK) which has recently commenced to do just this.

Biotechnological Solubilisation of Phosphate Rock

Crop P supply and associated plant growth and nutritional benefits have successfully been improved by fermenting PR with sugar beet wastes which has then been applied to the soil (Rodriguez *et al*., 1999). Research has also demonstrated that composting vegetable and other organic wastes can increase P availability to plants (Singh & Amberger, 1991). A review of studies undertaken by Vassilev & Vassileva (2003) concluded that agro-industrial wastes could be useful and cost effective feedstocks for these processes when combined with methods that biotechnologically solubilise PR. The hypothesis was that fungal solubilisation in the presence of C and N resulted in the production of organic acids which not only acidify the medium but also chelate the cations (in particular Ca^{2+}) bound to the phosphate. The P released by these processes is incorporated into the fungal mycelia, with any excess remaining in a soluble inorganic form. Despite the success of this approach on a small, laboratory scale, the technology has not been upscaled to the field or beyond. Thus our project had two main aims, (i) to identify and understand the mechanisms which contribute to increased P availability during the fermentation of PR and agro-waste products and after their application to the land and (ii) to cost effectively overcome the practical issues of utilising

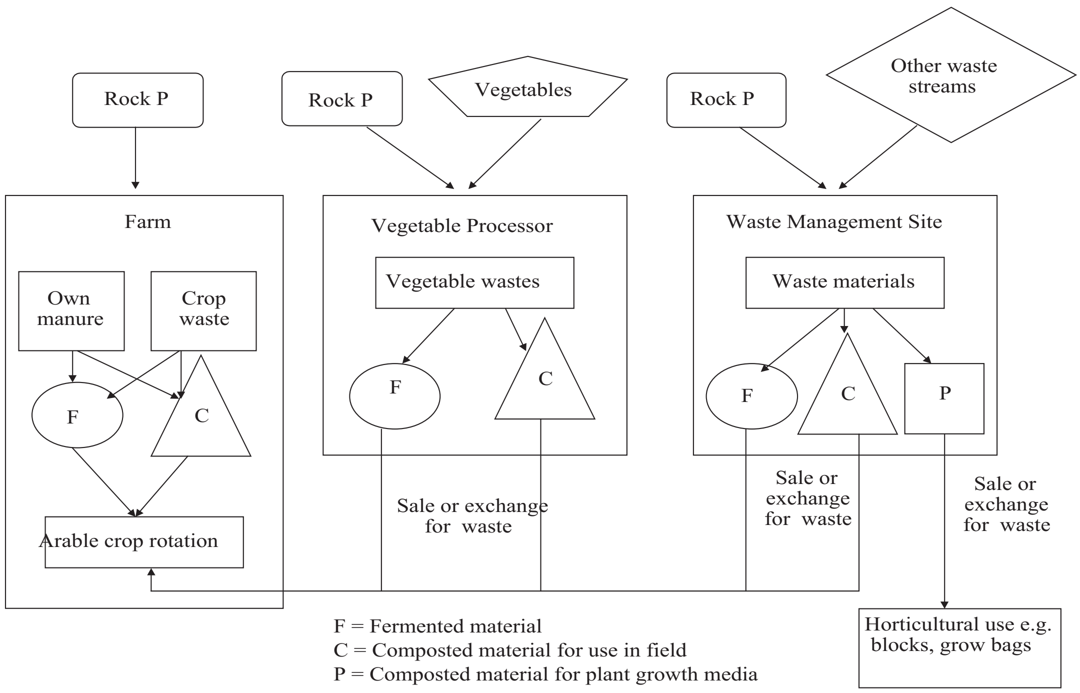

Fig 1. Diagram showing PR use and links with the waste streams for improved on farm P use efficiency.

the products developed using the technology in agricultural systems.

Three main points in the waste cycle of organic farming systems were identified by the project team as potential openings in which to apply the combination of PR and biotechnological solubilisation processes. These points were (i) on the farm itself; (ii) at packhouse or vegetable processing facilities; and (iii) at waste management and composting sites (see Figure 1).

Site managers were consulted to identify the seasonal variation and volume of their typical waste streams, as well as waste quality, particularly C:N ratio and C and N contents. Fermentation protocols that are being developed in the initial stages of the project in the laboratory will need to be practically applied within the constraints of the larger scale production facilities that are available to the project team.

P Uptake Efficiency by Crop Rotations

The modification of soil properties such as structure and microbial activity as an indirect effect of changes to crop rotation design may impact on the availability of P to the crops. Suggestions have been made that P deficiencies, particularly in organic systems, may cause major problems to the yields over the course of a rotation due to the impact it can have on legumes and their N fixing capacity. Consequently, this project is also investigating agronomic approaches to mitigating any such circumstances, in particular by designing crop rotations that increase the P use efficiency of the system by including crops or cultivars with high P uptake efficiency, particularly as cover crops (Kamh *et al*., 1999). A range of crops will be quantified for their ability to utilise PR either alone or as part of the fermented / composted products described previously. The approach will encompass both small scale field plots as well as on-farm field trials which will be used to compare the standard farm rotation with those modified to increase P use efficiency. Crops are likely to include a brassica (e.g. mustard), a legume (e.g. lupins or beans) and a cereal (e.g. rye or buckwheat). Initially, these are likely to be grown as green manures and incorporated into the soil prior to a spring cash crop being sown, but as the project progresses, the crops may be grown to full maturity within the rotation. Below we report the first results of a laboratory study where crop wastes were fermented with PR in the presence of microbial inoculants in order to increase P released to solution.

Small Scale Fermentation Pilot Study

Materials and methods

Plant materials (carrot tops, cabbage leaves, straw and whole potatoes) were ground into approximately 1mm diameter fragments. These were mixed with PR (granulated at a range of 1-2 mm) at a concentration of 3 g L^{-1}, or left unamended. A Czapeck solution was prepared (containing no added P) which was inoculated with a suspension of *Aspergillus niger, Bacillus thuringiensis*, or left without inoculation. Czapeck solution: A. Glucose 20.0 g, Distilled water 150 mL; B. KCl 0.5 g, $MgSO_4.7H_2O$ 0.5 g, $FeSO_4.7H_2O$ 50.0 mg, $ZnSO_4.7H_2O$ 50.0 mg, $NaNO_3$ 1.0 g, Distilled water 150 mL; C. Agar 20.0 g, Distilled water 600 mL. Solutions A, B, and C were sterilised separately and the solutions were mixed aseptically. The temperature of the solution was below 50°C at the point at which the inoculants were added in order to avoid damage to the microbial populations. 50 ml of the solution was added to each of the substrates in order to achieve a substrate concentration of 2% equivalent dry weight. Flasks were loosely capped and incubated at 25°C for 28 days. Flasks were incubated in two incubation chambers maintained at the same temperature in order to allow two replicates of each treatment to be present in each chamber; these acted as blocks in the experimental design. Treatments within each incubator were completely randomised. At the end of the experiment, each sample was mixed, and the weight of each recorded. From this, 20 g was mixed at 2:1 ratio with deionised water shaken for 30 mins at 100 rev/min and used to quantify water soluble P using well established laboratory techniques.

Results and Discussion

The initial experiment showed markedly different release of phosphate from the treatments (Fig. 2) and the general findings of Rodriguez *et al*. (1999) were corroborated. P was generally made more available from the treatments with P added as PR irrespective of the inoculant or substrate

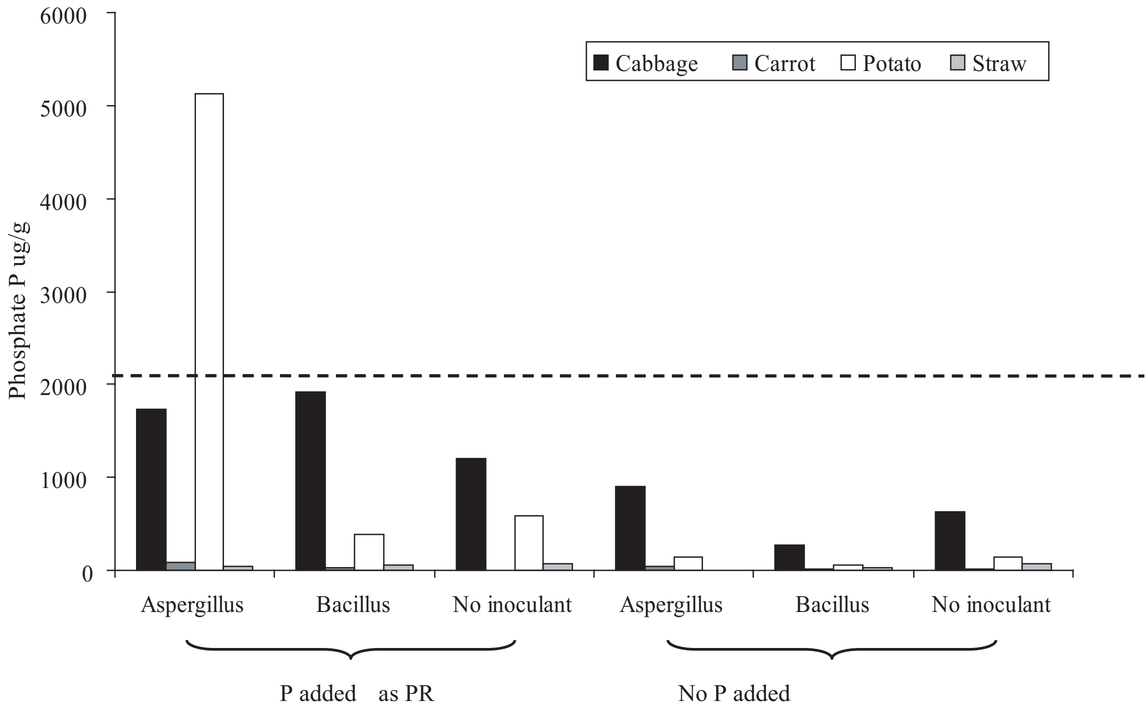

Fig. 2. The phosphate after four substrates were incubated under two PR treatments and three inoculant treatments.

used. A substrate / inoculum dependence was observed, with increased phosphate-P restricted to *Aspergillus* with cabbage and potato, and *Bacillus* with cabbage. The relatively low C:N ratio of cabbage was thought to be a factor in the increased P availability afforded by this treatment as it would be a useful nitrogen source for the microbial communities. The large increase in P availability with the potato in the *Aspergillus* treated with additional PR was more difficult to explain, as the C:N ratio was higher than for cabbage. However, it could be the type of C (i.e. high starch) was of primary importance here as it would be a useful energy source for fungal activity, although why the *Bacillus* treated product responded differently is unclear. Further experiments designed to understand these relationships more clearly are currently underway. Although not shown here, the variability of the data increased as phosphate-P increased. Furthermore, the biomass-P pool contained significant quantities of P that may provide an important source of useable P for the following crops when the microbes decompose.

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