Foliar Fertilisation of Wheat Plants with Phosphorus

A thesis submitted to The University of Adelaide

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Courtney Anna Emelia Peirce

School of Agriculture, Food and Wine

The University of Adelaide

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Abstract

Phosphorus (P) is an important macronutrient essential for plant growth. Broadacre cropping often requires additional inputs of mineral P fertiliser to grow profitable crops. Current management practice is to apply all fertiliser P at sowing. If the conditions under which foliar applied P could reliably increase grain yield are met, foliar application of P could be used as an in-season management strategy to top up P supply of wheat. This could be of significant benefit to farmers to reduce risk in regions with variable climate.

Through a series of plant experiments under controlled environmental conditions, this thesis investigated plant physiological (leaf wettability and growth stage) and foliar formulation (form of P, P concentration, adjuvant choice and pH) factors affecting the efficacy of foliar P uptake and translocation. The first experiment investigated the influence of leaf side and its corresponding wettability on the uptake and translocation of foliar applied P. The second and third experiments examined the effect of adjuvants on the wettability of wheat leaves and the associated uptake and translocation of foliar applied P (from phosphoric acid) after a few days and when harvested at maturity. The last experiment investigated the effect of foliar formulations differing in pH, P source and adjuvant, on wheat growth and uptake and translocation of P.

A number of methods and techniques were used throughout the thesis. Investigations on the effect of leaf morphology on uptake and wettability involved the use scanning electron microscopy. Wettability of leaves by both water and fertilisers was characterised using contact angle measurements with a combination of static, advancing, receding and spreading contact angles over time measured. Uptake and translocation of the foliar applied fertilisers was quantified through the use of dual or single labelling isotopic tracer techniques.

Absorption and subsequent translocation of foliar applied P was higher for the adaxial (upper) leaf side despite it being more difficult to wet than the abaxial (lower) side. When the foliar P concentration was increased the contribution of foliar P to plant P uptake increased but was translocated away from the site of application at a lower efficiency, likely due to the higher scorch experienced by the leaves at higher concentrations. Importantly, the morphology of the wheat leaf influenced both the retention and contact angle of the fertiliser on the leaf surface and the uptake and subsequent translocation of the foliar applied P. Foliar application of P at ear emergence had higher absorption and subsequent translocation of P than when applied at anthesis.

The inclusion of a surfactant in the foliar P formulation is essential because wheat leaves are difficult to wet. Application of foliar P without a surfactant resulted in lower levels of fertiliser retention on leaves. When applied with phosphoric acid the choice of adjuvant affected the spreading dynamics and leaf wetting area but did not affect the foliar uptake of P. The yield response to foliar applied phosphoric acid was inconsistent despite the uptake and translocation being the same for all formulations that included a surfactant. The timing of application was more important than surfactant choice with higher translocation of foliar applied P when it was applied at flag leaf emergence compared to tillering.

While increases in P uptake by wheat plants with foliar application of phosphoric acid were consistent, increases in plant growth and yield were not. Although foliar P from phosphoric acid was absorbed, only a small proportion was translocated. Specific combinations of adjuvant and P sources other than phosphoric acid were able to increase both plant P uptake and peak biomass. These foliar fertilisers ranged in associated cations (potassium, sodium and ammonium phosphates) and pH (2.2, 4.3, 6.5 and 8.7). Increases in plant P uptake did not always translate to biomass increases with translocation of foliar applied P playing a more crucial role than foliar uptake of P.

This thesis has made important progress in our understanding of the effects of wheat leaf morphology, leaf wettability and crop phenology on the recovery of foliar applied P fertilisers in wheat plants. The processes of retention, absorption and translocation of foliar-applied P have proven important for inducing positive biomass and grain yield responses and this has been achieved using several foliar P formulations. However, a single characteristic of the formulation that optimises these processes has not been identified and as a result prediction of the exact scenarios when positive responses of wheat to foliar-applied P should occur has not been achieved. It appears that there is some plasticity in the response by wheat plants to additional P supplied via the leaves and some remaining uncertainty about the effects of scorch that are influencing the predictability of the response. Field validation is required to ascertain whether the positive response found in controlled experiments can be replicated when environmental conditions are more varied and unpredictable.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or tertiary institution without the prior approval of The University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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I would like to dedicate my thesis to my Grandmas. Although they may not have understood my research, they still asked how it was going whenever they saw me. It was difficult to lose them during my PhD, but I am sure they would have been proud of all I have achieved.

List of publications and presentations

Peer-reviewed research articles

Fernández V., Guzmán P., Peirce, C., McBeath T., Khayet M., McLaughlin M. J., 2014, Effect of wheat phosphorus status on leaf surface properties and permeability to foliar applied phosphorus, Plant and Soil 384, 7-20, DOI 10.1007/s11104-014-2052-6

Peirce C. A. E., McBeath T. M., Fernández V. and McLaughlin M. J., 2014, Wheat leaf properties affecting the absorption and subsequent translocation of foliar applied phosphoric acid fertiliser. Plant Soil 384, 37-51, DOI 10.1007/s11104-014-2245-z

Peirce C. A. E., Priest C., McBeath T. M., McLaughlin M. J., 2015, Uptake of phosphorus from surfactant solutions by wheat leaves: spreading kinetics, wetted area, and drying time. Soft Matter 12, 209-218, DOI: 10.1039/c5sm01380a

Abstracts from presentations in scientific meetings

Fernández V., Guzmán P., Peirce, C., McBeath T., Khayet M. and McLaughlin M. J., 2013, Effect of phosphorous nutrition on wheat leaf surface properties, XVII. International Plant Nutrition Colloquium, Istanbul, Turkey, 19th-22nd August 2013. (poster presentation)

Peirce C., Facelli E., McBeath T., McLaughlin M. J., 2015, 'Topping up' wheat with foliar P: getting the right combination of P formulation and adjuvant, 2015 Agronomy Conference, Hobart, Tasmania, Australia 20th-24th September 2015 (short oral presentation)

Peirce C. A. E., Priest C., McBeath T.M. and McLaughlin M.J., 2015, Wetting and Uptake of Phosphorus Foliar Fertilizer by Wheat Leaves. The Australian Colloid and Interface Symposium, Hobart, Tasmania, Australia 1st-5th February 2015. (poster presentation)

Peirce C., Priest C., Facelli E., McBeath T., McLaughlin M. J., 2014, The effect of adjuvant on leaf wetting and uptake of fluid foliar P fertilizers for wheat. Fluid Forum, Scottsdale, Arizona, USA 17th-18th February 2014. (oral presentation)

Peirce, C., Fernández V., McBeath T., McLaughlin M. J and Guzmán P., 2013, Foliar uptake of phosphorus by wheat is greater from the adaxial than the abaxial leaf side, XVII. International Plant Nutrition Colloquium, Istanbul, Turkey, 19th-22nd August 2013. (poster presentation)

Industry publications

Facelli E., McBeath T., Peirce C., McLaughlin M., Hunt E., Montalvo D., 2015, 'Topping Up' Wheat with Foliar P – Does it work? In Proceedings of the 2015 Fluid Forum, Scottsdale, Arizona, USA, Fluid Fertilizer Foundation, Manhattan, Kansas, USA.

McBeath T., Facelli E., Peirce C., McLaughlin M., Hunt E., 2015 "Topping Up" Wheat with Foliar P – Does it work? In Proceedings of the GRDC Grains Research Update for Advisors, Adelaide, SA, 2015

Peirce C. A. E., Facelli E., McBeath T. M., McLaughlin M. J., 2014, Tactical foliar phosphorus (P) fertilisation of dryland crops in WFN Farm Bulletin Spring Editions 2014, Wimmera Farming Network

Peirce C., Priest C., Facelli E., McBeath T., McLaughlin M. J., 2014, The effect of adjuvant on leaf wetting and uptake of fluid foliar P fertilizers for wheat. In Proceedings of the 2014 Fluid Forum, Scottsdale, Arizona, USA, Fluid Fertilizer Foundation, Manhattan, Kansas, USA

Structure of the thesis

This thesis is presented in the publication format and includes papers that are have been published or prepared for submission to a journal.

Chapter 1 introduces the thesis and gives an overview and general discussion on the rationale behind why we were interested in researching foliar fertilisation of wheat with phosphorus. It also provides an overview of the literature relevant to my research as put together for my initial research proposal in July 2012. As a result, more recent publications are not included in the literature review but are discussed where relevant in the discussion sections of the subsequent chapters. This chapter concludes with the aims and objectives of my thesis.

Chapter 2 describes an experiment published in *Plant and Soil* investigating the uptake and translocation of foliar applied phosphoric acid to the adaxial (upper) and abaxial (lower) sides of wheat leaves. The influence of leaf morphology and structure on both wettability and uptake of foliar fertilisers was explored.

Chapter 3 presents the results of collaboration with the Ian Wark Institute at the University of South Australia, which investigated the spreading and wettability of the phosphoric acid based formulations containing different adjuvants on wheat leaves and the initial uptake and translocation of P seven days after foliar application. This paper investigated the dynamics of wetting of wheat leaves by various phosphoric acid based formulations and has been published in the interdisciplinary journal *Soft Matter*.

Chapter 4 comprises a paper that follows and expands on Chapter 3 by investigating the effect of timing of application and the use of adjuvant with phosphoric acid on the wettability and surface structure of wheat leaves, as measured by contact angles and scanning electron microscopy, in combination with the uptake and translocation of five phosphoric acid formulations that differed in choice of adjuvant measured using isotopic techniques. The plants were grown through to maturity which allowed measurement of the final sink of the foliar applied P and the resultant yield effect.

Chapter 5 presents the last experiment focussing on the evaluation of fertiliser formulation through a plant experiment grown through to peak biomass with 21 different P formulations tested (seven P products × three adjuvants) that varied in both pH and associated cations. This experiment was designed due to a lack of consistent biomass results and low translocation achieved with phosphoric acid.

Chapter 6 summarises the main findings of my thesis and concludes with future recommendations for work in this area.

In the Appendix is a preliminary paper published in *Plant and Soil* on which I am third co-author on the effect of plant P status on leaf wettability and foliar P uptake. This study, conducted in collaboration with Victoria Fernandez, a visiting plant physiologist from Spain, was instrumental in developing my understanding of plant surfaces and microscopy techniques early in my PhD candidature. Importantly, this paper demonstrated that foliar applied P will not be effective for correcting severely deficient plant P status and should only be used under conditions of marginal soil P status.