How do P Fertilizer Rates and Placements Affect N-Fixation in Field Pea

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Abstract

Different placements and rates of P fertilizer were applied to field pea (*Pisum sativum*) to determine which had the greatest effect on N-fixation, germination and nodulation. Phosphorus fertilizer was provided as monoammonium phosphate (MAP) and triple superphosphate (TSP). Fertilizer was either seed-placed (SP) or side-banded (SB). It was found that there were no negative effects on germination or nodulation and MAP which was seed-placed at a rate of 20 lb ac^{-1} had the greatest significant effect on N-fixation.

Introduction

Due to their adaptability to harsh growing conditions, production of high quality forage and food, and capability in maintaining sustainable farming systems, growing pulse crops has become a popular practice in the semi-arid northern Great Plains (Miller et al., 2002). Pulse crops are being utilized in crop rotations by producers not only as a source of income but also a source of nitrogen (N) inputs for latter years. It has been estimated that 50-70 Tg N is fixed annually through various pathways in agricultural systems (Herridge et al., 2008), and a total of 122 Tg N gets fixed including natural and agricultural systems annually (Burris, 1980). This identifies pulse crops as large-scale players in the global N cycle.

Worldwide area planted to pulse crops tops 170 million acres (Herridge et al., 2008). With over 4.59 million acres of pulses, Saskatchewan is Canada's main producer of chickpea, lentil and pea (Saskatchewan Pulse Growers, 2009). Pea production rose from 1.36 million acres in 1995 to 2.89 million acres in 2008, producing over 3.2 million tons (Saskatchewan Pulse Growers, 2009). As the price of inorganic fertilizers continues to rise, these crops will continue their importance as a secondary source of nutrients for crops in subsequent years.

One common misconception made by some producers about pulse crops is that they are 'no input crops' due to their nitrogen fixing ability. This means that they may not need nitrogen inputs in their production year, and will provide some nitrogen inputs for subsequent years via decomposition of residue. Nitrogen fixation by legume crops is an energy consuming process and it normally requires a high concentration of phosphorus (P) in nodules (Wen et al., 2008), thus, P demand is high for legumes and P fertilization is very important for their production (Cocks and Bennett, 1999). This information and the following study hypothesize that P inputs increase N-fixation in legume crop production through increased host plant production.

Phosphorus' Role in N-Fixation and P Fertilizer Effects on N Fixation

There are four phases at which mineral nutrients may influence the symbiotic N fixation of leguminous plants; host growth, growth and survival of rhizobia, infection and nodule development, and nodule function (Robson, 1978). Specifically, P's influence on symbiotic N-fixation in legume species has been given a considerable amount of study, but its role in the process still remains unclear (Israel, 1987).

The concentration of P in root nodules is three times higher than in other organs, and the ratio of P distribution will not change even under P deficient conditions, despite that the nodule dry-weight could be reduced (Ribet and Drevon, 1995; Vadez et al., 1999). More P may be required in nodules in N fixation processes than in plant growth (Olivera et al., 2004). Improving the management of P to enable legumes to achieve high N fixation rates will be a critical aspect of increasing legume production (Sinclair and Vadez, 2002).

Negative Impacts of Phosphorus Fertilizer

Phosphorus fertilizer has somewhat negative connotation with producers due to its toxicity to pea seedlings. The maximum recommended rate of seed placed P fertilizer (as monoammonium phosphate) given by Saskatchewan Agriculture is 15 lb ac^{-1} of P_2O_5 (Saskatchewan Agriculture). Henry et al. (1995) found that pea stand counts 3-4 weeks after seeding were inversely proportional to the rate of seed placed P, with the stand count being reduced by 50% at their highest rate of P (39 lb P ac^{-1}).

The effect of seed-placed P fertilizer can be dependent on P fertilizer type. While Henry et al. (1995) found seed placed monoammonium phosphate (MAP) had an inversely proportional negative effect on pea stand counts, McKenzie et al. (2001) found that seed-placed triple superphosphate (TSP) had no effect on pea yield even at their highest application rate (23 lb P ac^{-1}). This smaller impact of seed placement was likely due to the lower ammonium (0 vs. 11%) and salt index (0.210 vs. 0.485) of TSP than MAP (Tisdale et al., 1985). McKenzie et al. (2001) concluded that the similar response for seed-placed and banded placements of TSP indicates that pea is likely insensitive to placement of TSP.

Objectives

The objectives of this research are to quantify P fertilizer effects on N-fixation in field pea (*Pisum sativum*). More specifically, to measure P fertilizer rates and placement effects on seedling emergence, nodule formation and total N-fixation. Also of interest is to quantify the effect of TagTeam® (Novozymes Inc., Saskatoon, SK) which is an inoculant that contains *Penicillium bilaiae* and *Rhizobium leguminosarum*, on N-fixation, seedling emergence and nodule formation. These results will be compared to P fertilizer treatments as an option suitable for organic management.

Methods

The effect of P fertilizer rate and treatment along with the inoculant TagTeam® on N-fixation and seedling emergence was investigated in a field experiment. Two field sites were chosen which had a low to moderate soil P test level (threshold <20 lb ac^{-1}) and results from one of these sites at Langham, SK will be discussed.

Phosphorus fertilizer in this study was either seed-placed (SP) or side-banded (SB). Side-banded is when the fertilizer is placed one inch to the side and one inch below the seed row to minimize contact with the seedling. The maximum safe rate of seed-placed monoammonium phosphate fertilizer as recognized by Saskatchewan Agriculture is 15 lb ac^{-1} of P_2O_5 (Saskatchewan Agriculture). The fertilizers that were utilized in this study are monoammonium phosphate (MAP – 12-51-0-0) and triple superphosphate (TSP – 0-45-0-0). MAP is a P-based fertilizer that is commonly used by producers in Saskatchewan. TSP is a fertilizer which is not often used by producers in Saskatchewan but is included because it does not contain any N, which may interact with the N-fixation process. Due to the differences in salt status in these two fertilizers, they cannot be compared to each other directly, however, it will be discussed which one has the greatest positive effect on N-fixation.

There were eleven treatments. Pea will be inoculated with commercial *Rhizobium* inoculant prior to sowing (N-Prove, Novozymes Inc., Saskatoon, SK). There was a control treatment (treatment 1) with no additional fertilizer. Three rates of MAP (10, 20, and 30 lb ac^{-1}) and three rates of TSP (10, 20, and 30 lb ac^{-1}) were seed placed (treatments 2-7). Three more treatments of MAP (10, 20, and 30 lb ac^{-1}) were banded near the seed (treatments 8-10). The fertilizer rates in this study are in terms of product, but the treatments are approximately 5, 10, and 15 lb ac^{-1} of P_2O_5. Another treatment with organic management implications was also included (treatment 11). In this treatment, seed was treated with the recommended rate of TagTeam® (*P. bilaiae* and *Rhizobium* combined, Novozymes Inc., Saskatoon, SK). Treatments were established as a randomized complete block design and replicated six times. A wheat strip was sown along the end of each replicate block, as it was used as a reference crop in the ^{15}N isotope dilution assay. The treatments are summarized according to rate and placement in the following table:

Table 1. Treatments of P Fertilizer Applied and Their Associated Rates and Placements. SP means P Fertilizer Source is Seed-Placed; SB Means Fertilizer is Side-Banded.

Treatment	Inoculated	P Fert. Source	Placement	Rate Product (lb ac^{-1})
Control	yes	none	N/A	0
MAP SP 10	yes	MAP	SP	10
MAP SP 20	yes	MAP	SP	20
MAP SP 30	yes	MAP	SP	30
TSP SP 10	yes	TSP	SP	10
TSP SP 20	yes	TSP	SP	20
TSP SP 30	yes	TSP	SP	30
MAP SB 10	yes	MAP	SB	10
MAP SB 20	yes	MAP	SB	20
MAP SB 30	yes	MAP	SB	30
TagTeam®	yes	TagTeam	N/A	N/A

A ^{15}N isotope was applied to microplots within each pea plot and its paired wheat strip to determine N-fixation. The ^{15}N isotope was only applied to the first four replicates because of the high cost related to the highly enriched ammonium nitrate. The microplot position was selected based on consistency; it had to be representative of the plot as a whole and it needed to be close to the wheat strip. Ammonium nitrate solution containing ^{15}N was applied at a rate of 5 kg ha^{-1} and enrichment of 10 atom%.

Due to P fertilizer's known toxic effects on pea seedling germination and emergence; emergence counts were performed to determine P fertilizer rate and placement effects on pea seedlings. Two weeks after emergence the number of seedlings were counted. Two 1 m rows per plot were counted, one row at the front and one row at the back of the plot. Following this, in mid July, five plant roots per plot were harvested; nodules counted and stem growth measured. This information was used to assess possible negative effects on nodulation.

Prior to final harvest (at maturity) ^{15}N microplots were hand harvested. Pea seed and straw were separated by hand, and then subsamples of seed and straw were taken. Wheat microplot seed and straw are not separated; the whole plant is ground (seed and straw together). Wheat is ground as a whole because it is used as a proxy for the soil, so only total ^{15}N in the tissues are of concern. The samples were then processed through a mass spectrometer which yielded ^{14}N: ^{15}N ratio. Nitrogen derived from the atmosphere (%Ndfa) was then calculated according to Hardarson and Danso (1990). In this method the ^{15}N uptake by the legume is compared to the ^{15}N uptake of the reference (wheat). The reference crop only has a single source of N available to it (soil N – including fertilizer N) and provides an estimate of ^{15}N from the soil. The legume has two sources of N available to it, soil N and atmospheric N through N-fixation. The amount of dilution of the soil ^{15}N by atmospheric N through fixation is calculated, thus providing an estimate of N-fixation. The equation for determining %Ndfa as determined by Hardarson and Danso (1990) is given below:

$$\%NDFA = \left(1 - \frac{atom\%\ 15N\ excess\ (fc)}{atom\%\ 15N\ excess\ (nfc)}\right) \times 100$$

Results and Discussion

The results presented are results produced from a site approximately ten kilometres west of Langham SK. The pea crop was grown in the summer of 2009, a cold summer which was also somewhat dry, with the weather finally warming up in September which made the harvest of many crops in the province possible that year.

In terms of plant germination, there was no significant difference between any of the treatments. The control plots had a mean of 15 plants per meter, and the highest emergence of any other plot was the MAP SB 30 treatment which had a mean emergence of 17 plants per meter. The lowest mean emergence was shown in the control, MAP SP 20 and MAP SB 30 treatments with approximately 15 plants. This shows that none of the treatments had a negative effect on plant germination which is a good sign for producers who may be worried about the potential negative effects associated with P fertilizer.

Although nodulation was not significantly affected by fertilizer rate or placement it was more variable than germination. While there were no significant effects, in terms of mean treatment MAP SP 30 had an approximately 40% increase in nodules per shoot mass (Fig. 1). This again is good news for producers as there was no significant decrease in nodulation between any of the fertilizer treatments.

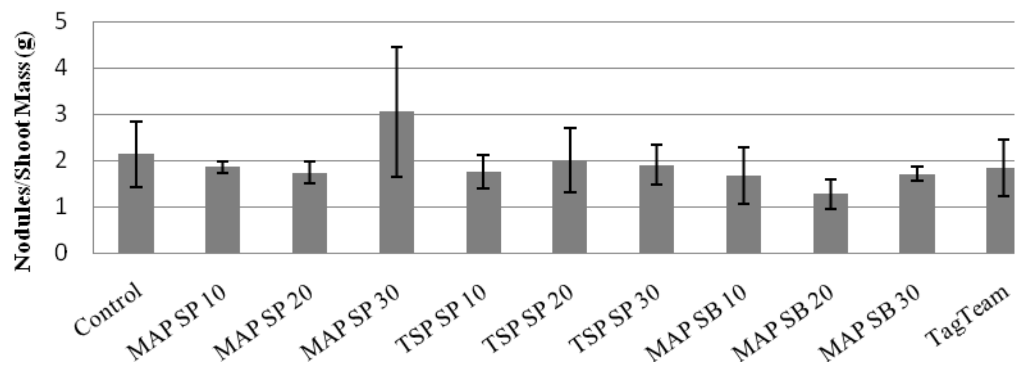

Figure 1. Nodule number per shoot mass in grams, Langham site, 2009.

Only one treatment significantly affected N-fixation, and this was MAP SP 20 (Fig. 2). While there were a few interesting tendencies, only MAP fertilizer which was seed placed at 20 lb ac^{-1} significantly increased the percentage of N which was derived from the atmosphere (%NDFA) in the pea seed and straw tissues (Fig. 2). All TSP treatments seemed to affect the N-fixation in a similar way, regardless of rate. The MAP side-banded treatments seemed to have an increasing effect on N-fixation, but without higher rates one cannot say whether it would have been significant (Fig. 2).

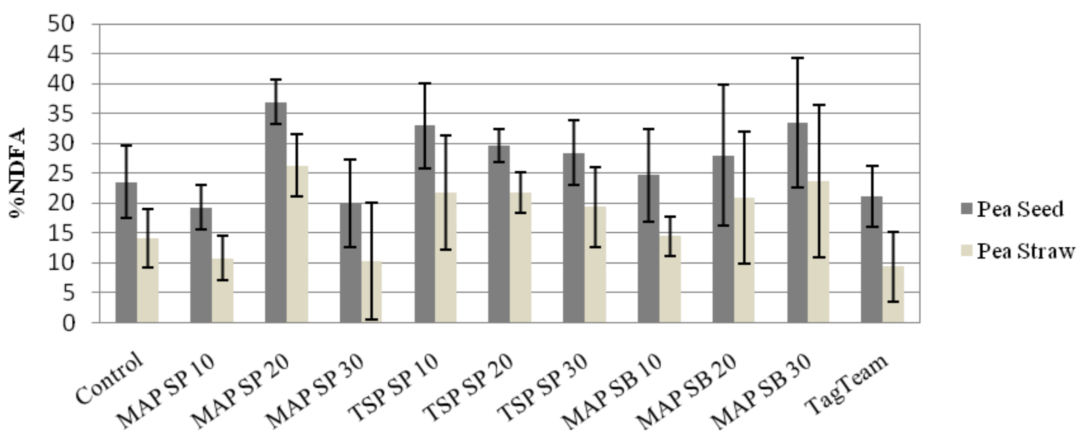

Figure 2. N-fixation (%NDFA) results from Langham, SK site, 2009.

While the emergence and nodulation data showed that there were no negative effects of seed-placed P fertilizer, it is important to test higher rates to determine where the threshold lies between maximum benefit from additional P and negative effects on germination and nodulation, as the weather in the summer of 2009 did not necessarily give the maximum conditions for N-fixation. Side-banded treatments of MAP fertilizer seemed to be on an upward trend of increasing N-fixation, but without more treatments this is impossible to determine. This may be due to the seedling not accessing all the P fertilizer which was placed in the band. Seed-placed

MAP fertilizer applied at 20 lb ac^{-1} resulted in the only significant increase in N-fixation. More treatments must be done with higher rates of P to determine whether more P can increase N-fixation while not significantly decreasing germination and nodulation.

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