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Inoculation and nitrogen management to optimize pulse crop yield and protein

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Nodule formation along the length of the tap and lateral roots with granular inoculant. Photo by P. Miller.

Abstract

Pulse crops require nitrogen (N) either from the soil or through N gas fixation by rhizobia bacteria in nodules on their roots. This article will discuss the factors affecting nodulation and N fixation, different inoculant types and their effect on yield and protein, starter and rescue N along with the need for other nutrients, and how the economics play out. Earn 1 CEU in Nutrient Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/597.

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Pulse crops—including peas, lentils, chickpeas, and faba beans—require nitrogen (N) either from the soil or through N gas fixation by rhizobia bacteria in nodules on their roots (Fig. 1). Given a choice, a plant will generally extract available N from the soil, rather than go through the carbon-expensive relationship with rhizobia. Most soils contain some N-fixing rhizobia; however, an inoculant with rhizobia specific to the pulse crop provides the most effective N fixation (McKenzie et al., 2001a).

Rhizobia nodulation begins two to three weeks after plant emergence, and these nodules become active after an additional one to two weeks at about the third node stage. Active nodules are pink to red inside. The amount of N fixed varies with pulse species (faba bean > pea > chickpea > lentil; Walley et al., 2007).

Factors affecting nodulation and N fixation

There are several factors that negatively affect nodulation and the resulting N fixation process. Nitrogen fixation can stop or slow after flower in the Northern Great Plains when conditions are dry (Fig. 2) and as plants mature (Fig. 3). Nodule activity is severely limited, and native rhizobia populations are lower in dry or waterlogged soil, at extreme soil temperatures, and in acidic and saline soils (Denton et al., 2013). However, inoculant strains and their host plants differ in pH and salinity tolerance (Bordeleau and Prevost, 1994). Rhizobia persistence in the soil is reduced under adverse soil conditions, especially when host plants are not present. In traditionally water-limited regions, practices that retain soil moisture, such as no-till, can enhance N fixation.

There are several practices that can improve nodulation and N fixation. It is important to use a species-specific inoculant applied at the proper rate although some inoculants are interchangeable among species, such as pea (but not chickpea) and lentil. Liquid and peat-powder seed-applied inoculants need to be kept cool and dark before application. Granular forms better protect their rhizobia. Contact with fertilizer in mixing or application equipment can kill bacteria. Similarly, some fungicides may not be compatible with inoculants (Kutcher et al., 2002).

The pulse/rhizobia system needs adequate phosphorus (P), potassium (K), sulfur (S), and micronutrients for optimal N fixation. Too much soil nitrate inhibits nodulation and N fixation (Fig. 3).

Inoculant type

Seed-coat inoculant is less expensive, but more challenging to properly care for before and during application, and sometimes less effective than soil-applied granular inoculant. Granular inoculant applied in the seed row or in a side band increased chickpea yield 8 of 12 years compared with seed-coat inoculant (Fig. 4). When compared with seed-applied peat-powder, granular inoculant produced higher protein, especially under drought conditions (Bestwick et al., 2018). Soil-applied granular inoculant also produced higher seed protein and yield with little or no N fertilizer (Clayton et al., 2004a), established nodules at a soil pH of 4.4 (though minimal), and had greater N fixation and plant biomass at a soil pH of 5.4 (Rice et al., 2000).

Granular soil-applied inoculant promotes rhizobia populations that are evenly distributed on tap and lateral roots, whereas seed-coat inoculant forms nodules clustered near the root crown (Fig. 5; Rice

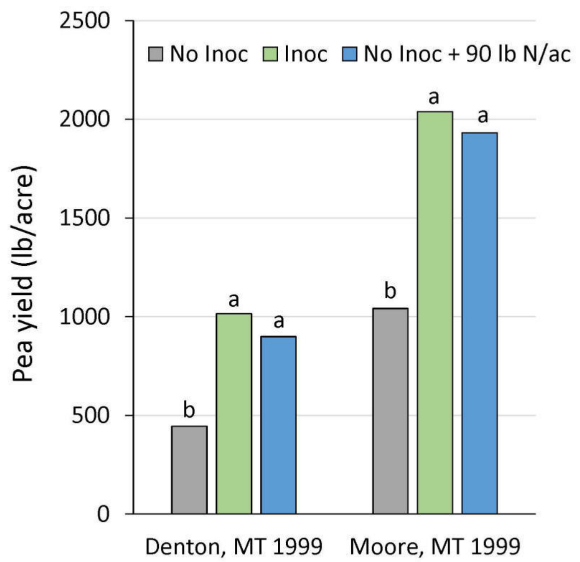

Fig. 1.

Pea grain yields with inoculant, without inoculant, and with N broadcast at seeding on fields without recent pulse history. Different letters denote significant differences with >95% confidence at a location (McConnell et al., 2002, MT).

Sidebar

Resources

Alberta Phosphorus Fertilizer Application in Crop Production: https://bit.ly/2lHjpa4

Alberta Potassium Fertilizer Application in Crop Production: https://bit.ly/2KwwA8G

IPNI/South Dakota State University Seed Damage Calculator: https://bit.ly/2MwOIjy

Montana Cool Season Pulse Production Guide:

Expand Sidebar

et al., 2000). Nodules on tap and lateral roots provide a benefit where surface soils may dry out or in low-pH soils with low populations of indigenous rhizobia. Some farmers use two forms of inoculant to decrease odds of inoculant failure.

Inoculant effect on pulse yield and protein

Inoculant is most effective in fields without recent pulse history and can increase protein under low spring soil nitrate levels. An Alberta study of 21 field trials with a mix of pulse crop history found yields increased from granular inoculant in 41% of trials (Fig. 6). When yields increased with inoculation, they were greater on fields without (15%) than on fields with (5%) a pulse history. Notably, inoculant did not increase yields in 54% of fields with no history of a pulse crop. Increases in seed yield were found at all spring soil nitrate-N levels, but the magnitude of yield increase was higher at low soil nitrate-N (Fig. 6).

Inoculant was far more likely to boost protein on fields with no pulse crop history than those with crop history and when spring soil nitrate-N levels are less than 18 lb N/ac. Protein is highly unlikely to increase with inoculation under high spring nitrate levels (greater than 36 lb N/ac; Fig. 7).

A two-year study conducted at three locations in Alberta found that granular inoculant provided adequate N to meet yield potential, without fertilizer N, while peat-powder seed-coated pea yields did not reach granular-inoculated pea yields regardless of N fertilizer rate (averaged across 20 to 70 lb N/ac N fertilizer rates). Seed protein averaged 19.4 and 17.6% using granular and seed-coat inoculant, respectively, and was not influenced by starter N (Clayton et al., 2004a).

Based on these studies, inoculant is more important in fields with no pulse history and with low soil nitrate. Also, granular inoculant often performs better than other forms.

Fertilizer N

Even though rhizobia in pulse crop nodules fix N, you might consider providing some fertilizer N if soil nitrate is low, especially on fields with no pulse history. Nodulation is carbon expensive, meaning it requires healthy plants. Since little N is contributed by nodules until the third node, N for initial growth must come from the top foot of soil. Nitrogen hunger can lead to plants getting "stuck"; that is, they can't grow to feed nodules, and nodules aren't actively providing N for growth. Rhizobia-fed pulses in low-nitrate soil take two to three weeks longer to get going than pulse plants with adequate soil or fertilizer N (P. Miller, personal communication). Finally, fertilizer N is insurance against nodule loss to pea leaf weevil, whose larvae feast on nodules.

There is a balance between enough soil nitrate for plant growth and too much N, which can inhibit nodulation, produce excess early vegetation, and reduce yield. Starter N can increase yield but not consistently based on an Alberta study (McKenzie et al., 2001a). Specifically, in 54 trials over four years, application of starter N had no effect on yield in 73% of trials, increased yield in 24% of trials, and decreased yield in 3% of trials relative to an unfertilized control (Fig. 8). In the 24% of trials where starter N benefited yield, yields increased by 8% with 18 lb N/ac and by 12% with 54 lb N/ac (McKenzie et al., 2001a). Neither spring soil nitrate-N, nor field pulse crop history influenced the impact of starter N on yield. The small yield increases from starter N contrasts with two Montana trials by McConnell et al. (2002) on fields low in soil nitrate (18 lb N/ac) without a pulse crop history in which pea yields doubled with the addition of 91 lb N/ac broadcast prior to seeding. The difference may be due to higher soil organic matter and native rhizobia populations in the Alberta than Montana soils.

The Alberta study found that starter N did not have a consistent impact on pea protein, regardless of field pulse history or spring soil nitrate-N level (Fig. 9). This is in general agreement with McConnell et al. (2002) and Clayton et al. (2004a) that inoculant is more likely to increase seed protein than starter N.

Pulse crops and rhizobia are very sensitive to fertilizer salts. The close proximity of seed row fertilizer N has greater negative impact on nodulation than high residual soil nitrate levels (Clayton et al., 2004b). If starter N is used at greater than low levels (e.g., >10 lb N/ac), it should be mid-row-banded or broadcast and incorporated before seeding.

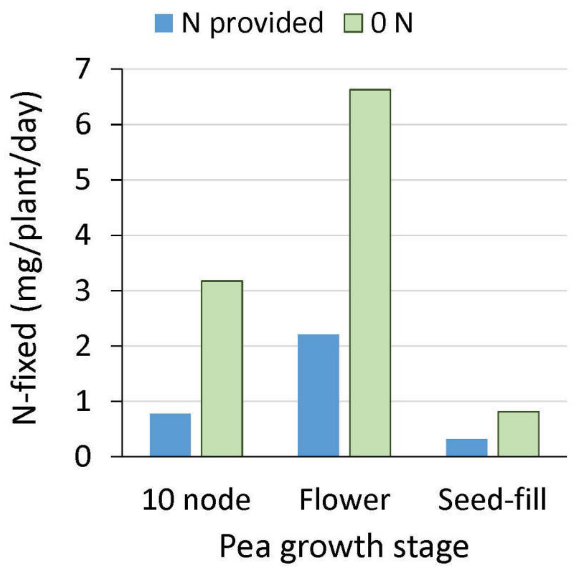

Fig. 3.

Nitrogen fixation is reduced as plant approaches maturity and with available N in a greenhouse study (Voisin et al., 2003).

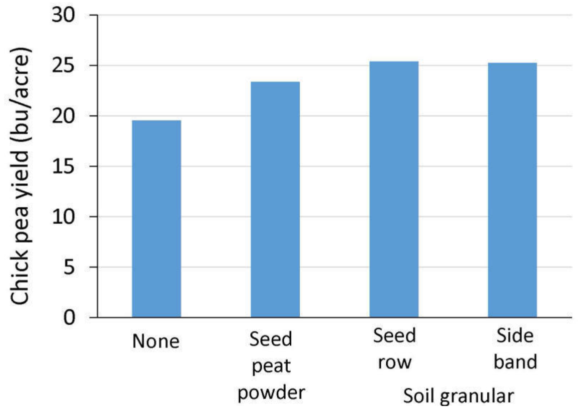

Fig. 4.

Chickpea yields with different inoculants, averaged over 12 site-years on fields with no pulse crop history for at least five years (Gan et al., 2005, SK).

Given these studies, it is reasonable to aim for 10–15 lb total available N/ac (soil + fertilizer) in the top foot in spring, keeping in mind that seed-row N may hurt germination. Starter N appears to be more important with seed-coat inoculant than granular inoculant (Clayton et al., 2004a). However, there is no guarantee that starter N will increase either yield or protein.

Rescue N

If nodulation failure is suspected as indicated by N deficiency (yellow lower leaves) and slow growth, dig and look for pink nodules. Rescue N can "salvage" yields if applied by four to six weeks after seeding (pea, 9–12 node, 7–10 leaf; chickpea, 10–13 node, 8–11 leaf; Fig. 10). If applied later, there is higher risk of too much vegetative growth, poor pod set, and delayed maturity. Rescue N requires rain/irrigation to move N into the soil where it can be taken up by plants. Although starter or rescue N may appear to boost early crop growth, yield gain may not offset N cost.

Other nutrients

Optimizing availability of all nutrients should increase N fixation and yield. Most nutrients are directly involved with nodulation and N fixation.

Sulfur is important for N uptake and protein production. If plants can't form protein, nodules will not be stimulated to fix N. Sulfur deficiency is indicated by yellow upper leaves. Soil tests are generally not a reliable indicator of S need in high-gypsum soils or soils that have sulfate below the usual 2-ft soil test level. Prior crop performance, crop S removal rates, and tissue concentrations can be used in combination to evaluate the potential need for S fertilization. Pulse crops remove twice the S in grain harvest (0.15 lb/bu) as wheat (0.08). On-farm experimentation may be the best method to test whether starter S will affect yield and protein.

Sulfate S (15–20 lb/ac) can be applied at planting as a side-band liquid or granular application. Pulse crops are very sensitive to sulfate in or near the seed row. Safe seed row rates depend on seed bed conditions (see IPNI/South Dakota State University seed damage calculator: https://bit.ly/2MwOIjy). Save the seed row for P and consider banking elemental S a rotation or two prior to the pea rotation (except in acidic soils since elemental S decreases pH) to avoid needing any sulfate in a pea year. Wen et al. (2003 in Saskatchewan) found 71 lb S/ac as elemental S applied with canola in a canola–barley–pea system provided sufficient S for above-average pea yields three years later. If the crop shows signs of S deficiency, consider 3–5 lb S/ac as granular or liquid. However, this will require rainfall to move the S into the soil and allow uptake by the roots.

Phosphorus is also important for N fixation, and at 0.67 lb P_2O_5/bu, a 40 bu/ac pea harvest removes more than 26 lb P_2O_5/ac. The response to P varies by species, variety, and growing conditions. In general, P response is more likely when Olsen P is less than 9 ppm. Several studies found yields increased with 30 to 40 lb P_2O_5/ac at such low soil P levels (Chen et al., 2006; McKenzie et al., 2001b; Karamanos et al., 2003). When Olsen soil P is greater than 13 ppm, up to 15 lb P_2O_5/ac can be added as a maintenance amount. This is approximately the maximum safe seed-placed rate on coarse soils. If soil tests and regional guidelines suggest higher P rates, side-band the additional amount at seeding, or build up P with the prior crop. Phosphorus is more likely to pay off with pulse forage than grain when soil P is near adequate (Wen et al., 2008). In lentil, starter P increased

Fig. 5.

Nodule formation in clusters near the soil surface with seed-applied inoculant (photo by P. Miller). Compare this with the first photo in this article showing nodule formation along the length of the tap and lateral roots with granular inoculant.

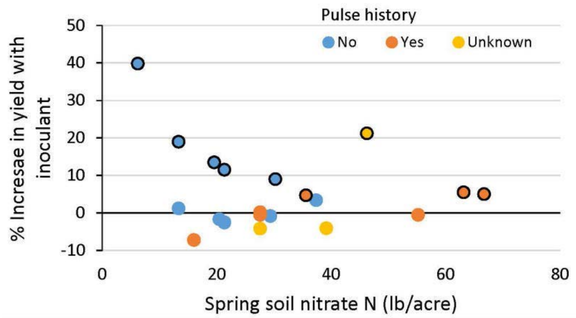

Fig. 6.

Percent increase in pea yield from inoculant for fields with different pulse history and spring soil nitrate-N level (McKenzie et al., 2001a). Black borders indicate significant increase or decrease at $P < 0.05$.

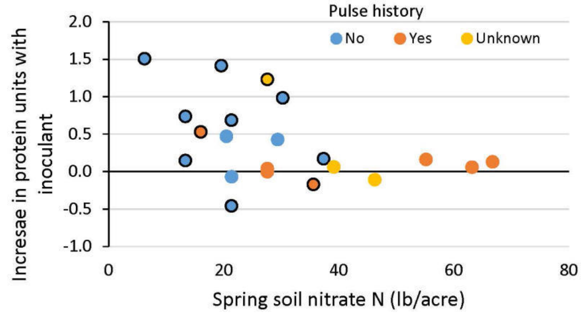

Fig. 7.

Increase in pea protein units from inoculant for fields with different pulse history and by their spring soil nitrate-N level (McKenzie et al., 2001a). Black borders indicate significant increase or decrease at $P < 0.05$.

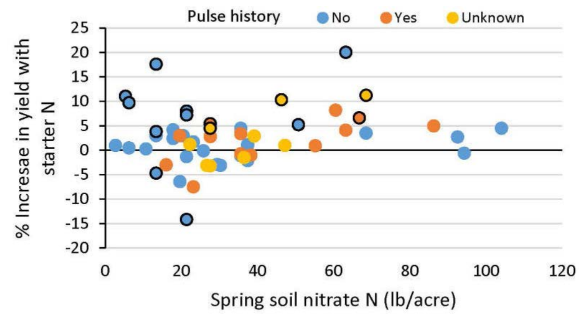

Fig. 8.

Percent increase in pea yield from starter N on fields with different pulse history and by their spring soil nitrate-N level (McKenzie et al., 2001a). Black borders indicate significant increase or decrease at $P < 0 .05$.

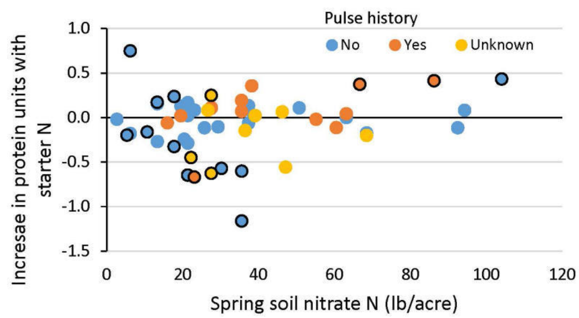

Fig. 9.

Increase in pea protein units from starter N on fields with different pulse history and by their spring soil nitrate-N level (McKenzie et al., 2001a). Black borders indicate significant increase or decrease at $P < 0 .05$.

harvestability (lowest pod being higher off the ground) but not pod production (Gan et al., 2004).

Potassium is also needed for N fixation, and pulses remove more than twice the amount of K_2O/bu (0.87) as wheat (0.38). It is generally not limiting in soils of the Northern Great Plains although it should be monitored in rotations with high removal of stems and leaves (forage, small grain straw) and in coarse soils. Potassium should not be seed-placed (except at low rates), but rather built up with the prior crop, or side-banded below the seed, at rates based on soil test levels and regional guidelines.

Most micronutrients are necessary for N fixation. Foliar applications of each of six individual micronutrients (boron, copper, iron, manganese, molybdenum, and zinc) shortly after the fourth node resulted in an average pea yield increase of 11 bu/ac in a very wet year in northeast Montana and 5 bu/ac in a dry year while a different nearby site saw little, if any, yield increase either year (Mohammed and Chen, 2018). Since yields increased even in soils with above-critical soil test levels, on-farm experimentation may be the best method to test micronutrient effects on yield and protein.

Economics

In an extensive review of dryland pulse production practices and net revenue across Saskatchewan (Grenkow et al., 2014), in low-yielding systems (<45 bu/ac), increased seeding rates showed the highest gain in net return. Starter N (30 lb N/ac) was the next best investment. Granular inoculant did not consistently produce higher net returns than liquid inoculant, but it is likely that pea and lentil had been grown on these fields, minimizing inoculant benefit.

In low-N soils, yields and protein may increase with starter N or inoculant, but until protein is more commonly rewarded with higher prices, the reward may not offset the cost. Yet, the risk of crop failure due to low N or failed nodulation may not be worth skimping on inoculant or low rates of starter N. For example, given soil acidification in the soil surface is a growing problem in traditionally neutral to alkaline soils (McFarland and Huggins, 2015; Sullivan et al., 2013; Engel, unpublished data), it may pay to test the pH of the surface soil and apply a granular inoculant if the soil is acidic.

Factors to consider when selecting an inoculant and starter fertilizer are spring soil nitrate levels, field history with pulses and inoculation, whether water is the likely yield-limiting factor, the chance of soils drying and nodules dying prematurely, soil conditions that limit nodulation and the indigenous rhizobia population, and whether a premium will be paid for protein.

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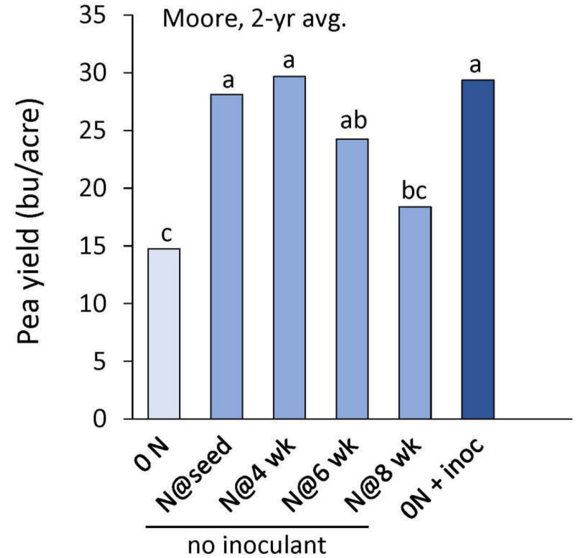

Fig. 10.

Rescue N (91 lb N/ac) can "save" pea yields if applied by the sixth week after seeding (pea 9–12 node stage, chickpea 10–13 node stage; McConnell et al., 2002, MT). Bars with at least one same letter are not different with at least 95% confidence.

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