4/Plant Nutrition

4/Plant Nutrition

Plant Nutrition Contents

continued...

Plant Nutrition

Inoculation

The soil atmosphere contains 78% nitrogen, but in a form unavailable to plants. Some bacteria, including Rhizobium, are able to convert this nitrogen into plant-available forms. This process, termed nitrogen fixation, can only occur when the rhizobia bacteria are in a partnership with a legume host plant.

• Nitrogen fixation is a symbiotic relationship and both the rhizobia and the plant benefit from the relationship.

The rhizobia bacteria responsible for nitrogen fixation normally live as independent microorganisms in the soil, and only fix nitrogen when in partnership with a legume. The partnership begins when the rhizobia come in contact with a legume root in the soil and recognize that root as an appropriate host plant. The rhizobia then enter the legume root through the small root hairs that are present on actively growing, young roots. The plant responds to this infection by developing a thickened nodule around the initial site of infection. Soon after the initial infection stages, the bacteria begin to multiply in the nodule and produce chemicals that they need to convert atmospheric nitrogen into a plant-available form. Interestingly, one of these chemicals is pink in colour, and causes the interior of the nodule to develop a dull pink to bright beefsteak-red colour.

• If the rhizobia are actively fixing nitrogen, the nodules will appear visibly red or pink inside when the nodule is sliced open.

Within the root, the legume host supplies the rhizobia with the energy (in the form of carbohydrates) that it needs to fix nitrogen and, in turn, the rhizobia supply the legume with plant-available nitrogen.

• Nitrogen fixation is synchronized with plant growth, supplying the crop requirements during rapid vegetative growth.

• Nitrogen fixation will supply most of the major legume crops with up to 80% of their total nitrogen requirements.

• Inoculated plants are more drought tolerant and higher in protein than un-inoculated plants.

• Inoculant is economical relative to its potential benefits and nitrogen fertilizer replacement value.

Many different kinds of pulse crops and many types or species of rhizobia are found throughout the world. In order for nodulation to occur, the rhizobia and the legume must be able to recognize each other. Recognition occurs through the exchange of a number of chemical signals. If the chemistry isn't right, nodulation will not occur.

• The relationship between the legume host and the rhizobia is specific – only certain species of rhizobia will nodulate specific legumes.

Inoculants contain rhizobia species that are suitable for specific pulse crops (Table 4.1). For example, the rhizobia that infect pinto bean will not infect lentil and vice versa.

• Chickpea is not a pea and pea inoculants will not nodulate chickpea.

Some rhizobia occur naturally in the soil and in long-term pulse land many rhizobia are already present and capable of causing nodulation and nitrogen fixation. Although some rhizobia may already be in the soil, these rhizobia may not be present in sufficient numbers or in the right place to ensure that the appropriate strain of Rhizobium contacts each legume plant as it develops root hairs. Therefore, the rhizobia must be placed with, or near, the seed – even if that same pulse has been grown previously.

• This process of inoculation

Table 4.1 *Specificity of Rhizobium species to pulse crop type.*

Pulse crop	Rhizobium species
Pea, lentil, faba bean	Rhizobium leguminosarum
Chickpea	Rhizobium ciceri
Dry bean	Rhizobium phaseoli
Soybean	Bradyrhizobium japonicum
Alfalfa, sweetclover	Rhizobium meliloti
Clovers	Rhizobium trifolii

is carried out each year a legume is planted to ensure that sufficient numbers of the correct strain of highly effective rhizobia are available where they are needed when the seed germinates.

• It is extremely important to properly inoculate chickpea as no native, indigenous Rhizobia occurs in Saskatchewan soils.

• It is important to ensure that first-time chickpea fields are inoculated with a high quality chickpea inoculant containing an effective strain for western Canadian conditions.

• Once introduced into the soil, the specific chickpea Rhizobium will survive, and numbers will likely increase with the frequency of chickpea plantings. However, each chickpea planting should be done with inoculated seed.

Inoculant formulations

Before 1988, all inoculant products were cultured and packaged in the USA, but today a number of companies in western Canada culture and formulate inoculants (Table 4.2). Single-strain products contain rhizobia specific for one crop, whereas mixed-strain products contain rhizobia suitable for two or more crops. For example, pea and lentil inoculants are frequently sold as mixed-strain inoculants. Both pea and lentil are nodulated by the same species (Rhizobium leguminosarum), but many different strains of this species occur and vary in terms of their effectiveness with different crops. Therefore, the manufacturer packages a mixed strain inoculant that contains a mixture of the best strain (or strains) for pea and the best strain (or strains) for lentil, although either will cause nodulation on both crops. Keep in mind that the best strain for lentil is not necessarily the best strain for pea. In contrast, single-strain inoculants contain only the rhizobia that has been identified as the best strain for that specific crop.

Manufacturers of multistrain inoculants argue that multistrain inoculants provide a level of insurance – if one strain fails in a particular environment, the second strain is likely to do the job. In contrast, manufacturers of single-strain inoculants argue that they have used only the best strain and, therefore, a less effective strain can not nodulate the crop. Both arguments have merit.

Manufacturers usually differ in the strains of rhizobia their respective inoculants contain, based upon in-house or external identification of effective strains. Some inoculants contain rhizobia identified for particular traits specific for certain environments. For example, some inoculants contain rhizobia that are particularly tolerant to cold environments.

Several different inoculant types, or formulations, are available: peat-based powder (with and without sticker), liquid, granular (peat-based and clay-based) and pre-inoculated seed (Table 4.2).

Peat-based powder inoculants require the use of a sticker. Commercial stickers are available for a nominal cost and are developed specifically for use with rhizo-

Table 4.2 *Rhizobium Inoculants*

Company	Product	Crop	Strain	Formulation
Agrium	Rhiz-Up	Pea, Lentil, Chickpea Dry Bean	Single	Liquid
Imperial Oil Products Div.	Enfix P	Pea	Single	Liquid
	Enfix L	Lentil	Single	Liquid
	Enfix B	Dry Bean	Single	Liquid
Saskatchewan Wheat Pool	BIOCOAT	Pea, Lentil	Proprietary	Pre-inoculated
Grow Tec	ProTec	Pea, Lentil, Chickpea, Dry Bean	Proprietary	Pre-inoculated
LiphaTech Inc.	Cell-Tech C	Pea, Lentil	Mixed	Liquid
	Nitragin Powder C	Pea, Lentil	Mixed	Peat
	Nitragin Powder-GC	Chickpea	Mixed	Peat
	Nitragin Brand D	Dry Bean	Mixed	Peat
	Nitra-Stik C	Pea, Lentil	Mixed	Self-stick peat
	Soil Implant C	Pea, Lentil	Mixed	Granular
	Soil Implant GC	Chickpea	Single	Granular
	Soil Implant D	Dry Bean	Mixed	Granular
Loveland Industries Inc.	Sow Fast P/L	Pea, Lentil	Mixed	Self-sticking peat
	Sow Fast Bean	Dry Bean	Mixed	Self-sticking peat
MicroBio Rhizogen	BioRhiz	Pea, Lentil	Single	Liquid
	MicroFix	Pea, Lentil	Single	Peat
	SelfStik	Pea, Lentil, Chickpea, Dry Bean	Single	Self-sticking peat
	Nodulator	Pea, Lentil, Chickpea, Dry Bean	Single	Granular
Philom Bios	N-Prove	Pea, Lentil	Single	Self-sticking peat
	TagTeam	Pea, Lentil	Mixed	Self-sticking peat
Urbana Laboratories	Liqui-Prep XT	Pea, Lentil	Mixed	Liquid
	Rhizo-Stick	Pea, Lentil, Dry Bean	Mixed	Self-sticking peat
Western Co-operative Fertilizers Ltd.	Westco Chickpea	Chickpea	Single	Self-sticking peat

bia. Homemade stickers can be used and include a dilute solution of powdered milk, honey, sugar, corn syrup, or wallpaper paste. Caution must be taken when using home-made stickers – some can be deadly to rhizobia. For example, commercial wallpaper pastes frequently are formulated with fungicides to prevent mold growth on walls, but these same chemicals may be deadly to rhizobia. Some milk replacers may contain antibiotics that will kill the rhizobia and should not be used; similarly cola soft drinks harm rhizobia.

The amount of sticker used is not critical, provided the seed is completely moistened, and any excess sticker is allowed to drain off. Two pounds of milk powder (900 g), or 1 pint (568 mL) of corn syrup, in one gallon (4.55 L) of solution will cover 1000 to 1500 lb (454 to 680 kg) of seed. Once the seed is wetted with the sticker, the inoculant can be added.

• **Typical application rates of**

1 lb (454 g) of peat inoculant to 300 lb (136 kg) of seed are generally adequate, but be sure to read the label.

Over application of inoculant has no detrimental effect in terms of nodulation. However, sticky, wet seeds can bridge during seeding. Use of inoculant at 2 to 3 times the recommended rate has no detrimental effect and ensures effective seed coverage, but it costs more.

The seed can be moistened with the sticker and mixed in an auger or cement mixer. The sticker may be applied to the seed with a garden sprayer as it flows from the truck or bin, and inoculant is often sprinkled on the moistened seed by hand. Other systems can be set up depending on available resources and the amount of seed inoculated annually. It is preferable to apply the inoculant in the auger immediately before seeding.

This process can be very messy and appropriate application rates of the inoculant difficult to meter. Bridging in the seed box can be avoided by allowing the moistened, peat-powder-inoculated seed to dry for an hour or so before it is loaded into the drill box.

Self-sticking peat inoculants are similar to peat-powder inoculants. However, a sticker is incorporated into the formulation. These inoculants are far more convenient than powder-peat formulation and easier to control application rates. With these inoculants adhesion to the seed is enhanced, if the seed is slightly damp during inoculation. This can be accomplished with a small backpack-type pressure sprayer emitting a very fine mist to the seed during auguring and inoculant application. Alternatively, wet the seed in the truck overnight with the deck tilted to facilitate drainage. This allows the seeds to swell and stay slightly moist, assisting in inoculant adhesion. This procedure may also prevent seed splitting and chipping, which may be a problem if the seed moisture content is low (< 13.5%).

Liquid-based products are more convenient to apply and slightly more costly than peat-based products. Application rates are more easily controlled. The liquid products are also more susceptible to damage from environmental extremes prior to seeding than peat-based inoculants. If treated seed is planted immediately into a moist seedbed, these formulations can be very effective. However, the window of opportunity for seeding is rather short, within 6 hours for some products, 24 hours for others.

Pre-inoculated seed is treated with a peat-based inoculant encapsulated with a seed coating. Pre-treated seed is ordered ahead of planting and no further inoculation is required.

Granular inoculants usually contain the same rhizobium strain as their peat or liquid counterparts (by their respective manufacturers). Granule formulations do not involve seed treatment; rather the product is accurately metered directly into the seed furrow with the seed, using existing equipment. Granular inoculants are sometimes referred to as "soil implants" because the placement inoculates the soil, not the seed. Presently, granular inoculants use either a granulated peat or a clay mineral as the carrier of the bacteria.

- **Peat granule recommended application rate is 5 lb/ac (5.6 kg/ha).**
- **Do not fill the application tank more than a half full as compaction can result in uneven application.**
- **Clay granules are recommended at a rate of 7 lb/ac (7.8 kg/ha).**
- **During application check the meter rollers occasionally for good flowability.**

Handling and Application

Inoculant products contain a live culture of rhizobia that can be easily killed by a variety of stressful conditions. Only live rhizobia are effective in nitrogen fixation. As such, inoculant should be used before the expiry date, and stored under refrigeration, if not used immediately.

Legume inoculants and pre-inoculated seed products are supplements, as defined by the Fertilizers Act, and are subject to registration and monitoring for quality control. Agriculture and Agri-Food Canada inspectors randomly sample inoculants from retail outlets; these samples are evaluated for quality control at federal laboratories. Occasionally, samples are deemed unsatisfactory (contain less than the required number of viable bacteria per gram of inoculant or per seed) and may provide less than desired field performance. Reasons for unsatisfactory product may be the result of the manufacturer, or unexpected and undetected conditions during inoculant formulation may have occurred.

- **This situation is very rare; manufacturers of inoculants incorporate quality control measures at all levels of manufacture and take great effort to ensure a quality product.**

Often, unsatisfactory ratings may be a consequence of improper shipping and storage conditions. Inoculants are very sensitive to high temperatures and desiccation during storage, and a decline in effectiveness can occur at the retail outlet.

- **Producers should check that retail outlets from which the products are purchased store them in a cool place out of sunlight.**

The purchaser can damage inoculants.

- **Once purchased, ensure that the product is kept cool and away from direct sunlight; check the label for additional storage.**

Best results are achieved if seeding is done soon after inoculation. When applying an inoculant during auguring, operate the augur at half capacity to allow adequate mixing and seed coverage. If using a liquid inoculant, shake the inoculant bag aggressively to evenly disperse the rhizobia before adding the inoculant to the seed in the auger. If the seed was previously treated with fungicides, read the application instructions to determine the safe limits for contact time. As a general rule, seed that is treated with a fungicide should be planted immediately after inoculation. Soil implant granular inoculant is less affected by fungicidal seed treatment than inoculants placed on the seed.

If seeding is delayed, the inoculated seed should be stored in a cool place, away from direct sunlight.

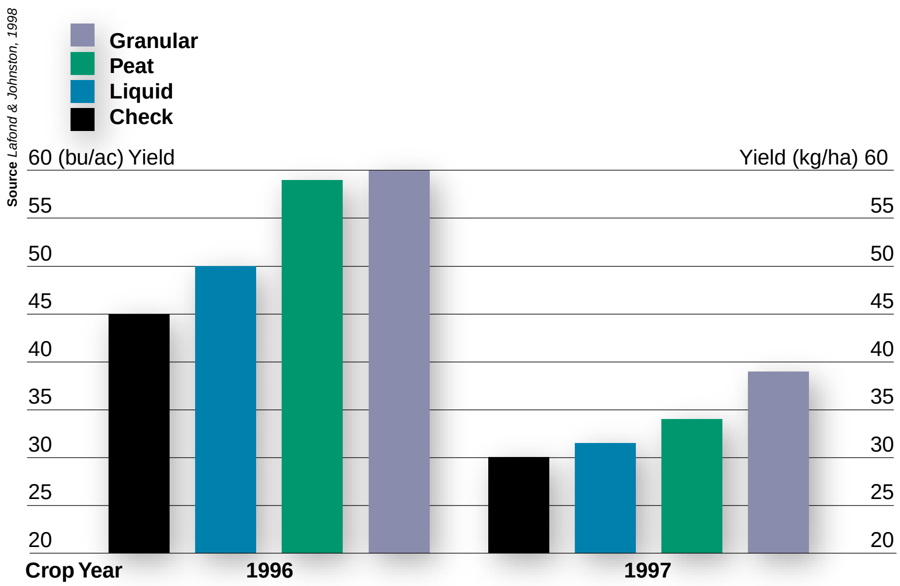
- **If seeding is delayed more than one day for peat-based inoculants, check manufacturer's recommendation for re-inoculating.**
- **Some liquid inoculant manufacturers suggest re-inoculation if delays from the time of application to when the seed is planted exceed 6 hours.**

Inoculated seed flows through seeding equipment more slowly, so calibration of the seeder is more accurate, if it is done using inoculated seed.

Inoculant Formulation

All inoculant formulations contain and deliver a high number of rhizobia and all can be very effective. However some distinctions can be made, depending on the mode of application. Peat powders, self-

Figure 4.1 *Influence of inoculant formulation on field pea yield. Pea yield trials at Indian Head*



sticking and liquid inoculants are all applied to the seed. Granular inoculants are applied directly to the soil in close proximity to the seed. Regardless of the formulation, it is important to read and follow the directions on the product label.

The **advantage** to seed treatment formulations is **every seed** receives rhizobia. However, **disadvantages** to seed-applied treatments include:

• Difficulty in achieving uniform application.

• Exposure to potentially harmful seed-applied fungicides,

• Potential harmful effects of seed coat metabolites released during germination (anti-bacterial exudates released as a component of the inherent disease resistance mechanism of the plant – rhizobia are bacteria).

• Little protection from desiccation occurs if seeding is delayed or seed is planted into dry soil.

• Liquid inoculants are particularly susceptible to desiccation problems.

• Potential movement of rhizobia away from the seed, particularly with respect to dry bean. Upon germination of dry bean, the seed coat, and attached inoculant, and cotyledons are carried toward the soil surface and away from the roots and root hairs.

Advantages to granular inoculant formulations include: the avoidance of contact with chemically-treated seed, high delivery rates of rhizobia, ease of application, and an increased ability to withstand seedbed moisture stress.

Disadvantages include:

• Product handling and storage, product delivered in 40 - 50 lb (18 - 22 kg) packages.

• Cost of product is significantly higher.

• Equipment requirements; two-tank pneumatic seeders are unable to deliver seed, phosphorus fertilizer and granular inoculant simultaneously.

• At present, blending granular inoculants and fertilizer is not recommended. Fertilizers are strong desiccants and can quickly kill the rhizobia and the two products can segregate in the tank.

Numerous research trials, comparing inoculant formulations, have been recently conducted in Saskatchewan with varying results. At Indian Head, granular inoculants have been very effective in pea production. Though yield potential differed between growing seasons, granular formulations produced the highest yields (Figure 4.1).

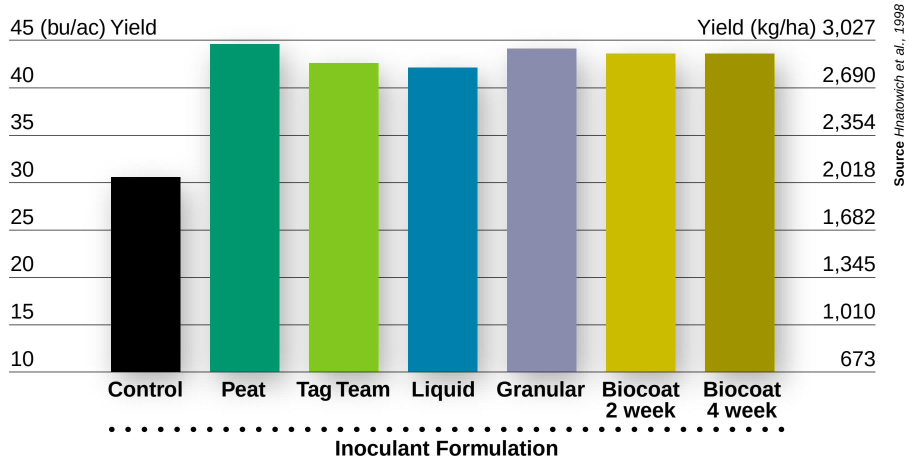
Although granular inoculants are often better than peat or liquid formulations, they are not always better. It stands to reason that all inoculant formulations should perform equally well under ideal conditions because all are simply "carriers" for rhizobia. Therefore, if the inoculant is properly applied and the treated seed is planted under ideal environmental conditions, differences due to inoculant formulations should disappear (Figure 4.2). In a study conducted in the Dark Brown and Black soil zones all inoculant formulations worked well. Pre-inoculated seed, treated four weeks prior to planting, still provided effective nitrogen fixation. TagTeam, a dual inoculant containing both a rhizobia bacteria and a phosphorus-solubilizing fungus can, under appropriate conditions, increase phosphate uptake.

Numerous factors can impact the effectiveness of inoculation. It is important to remember that nitrogen fixation is a symbiotic relationship. Anything that negatively impacts plant growth will also restrict nitrogen fixation. If the crop is harmed by herbicide residue, inappropriate application or timing of post-emergent herbicide applications, nitrogen fixation will decline. If planting seed contains residual traces of glyphosate, root development, and, particularly, root hair development, will be abnormal and nodules are unlikely to develop.

Plant stress will inhibit nodulation and restrict nitrogen fixation. Severely stressed plants will not form nodules. Cool, cloudy weather early in the growing season will delay nodulation. In the Brown soil zone, early seeding into dry, or rapidly drying soils can also reduce nodulation. If the legume crop is inadequately supplied with adequate plant nutrients, especially phosphorus, fixation will be reduced. Rhizobia do not tolerate saline soils, contact with damaging fertilizers (primarily due to the fertilizer salt effect), or extremes in soil pH. Fixation of some pulses can be dramatically reduced in the Peace River area of northern Alberta where soil pH levels are near 5.5. On low pH soils, increasing the inoculation application rate or using a granular inoculant is recommended.

The effectiveness of inoculation may also be influenced by the previous use of pulse crops in the rotation. Testimonial evidence suggests that, when planting inoculated pulse seed on fields with a past and repeated history of pulse production, response to inoculation is sometimes limited. It is suggested that indigenous, background rhizobia can effectively nodulate the crop. This may be the case. However, just as different varieties of pea have slightly different characteristics, the different Rhizobium strains may differ in their ability to fix nitrogen. Indigenous rhizobia may be very effective in forming nodules on legume plants, but may be inefficient nitrogen fixers. Likewise, introduced bacteria, by way of seed or soil treatment, can decline in nitrogen-fixing ability. Applying a high quality inoculant at seeding helps ensure that high numbers of efficient nitrogen-fixing bacteria will occupy the limited number of infection sites, where nodules form on the roots of a pulse crop.

Figure 4.2 *Influence of inoculant formulation on field pea yield under ideal conditions.*



The effectiveness of inoculation can be checked by examining the pulse crop in early summer. The best way to check for nodulation is to dig up a root and gentle wash off the soil in a bucket of water. Nodules are fragile and readily pull off if the roots are pulled out of the soil. Nodules should show up as swollen bumps that develop near

Source Philom Bios

Figure 4.3 *Good nodule development on a pea plant.*

the stem close to the soil surface (Figure 4.3). If nitrogen fixation is active, the nodules will be pink or red on the inside. Lack of nodules indicates that rhizobia did not infect the pulse plant. Lack of a pink colour (usually green or cream coloured) indicates that the rhizobia are not fixing nitrogen. Nitrogen fixation declines once plants begin pod formation and seed development.

Fertilization

Pulse crops have a high demand for plant nutrients and extract high levels from the soil for optimal plant yields. Most nitrogen, phosphorus and sulphur is accumulated in the seed and ultimately exported off farm with the seed,

Source Western Canada Fertilizer Association

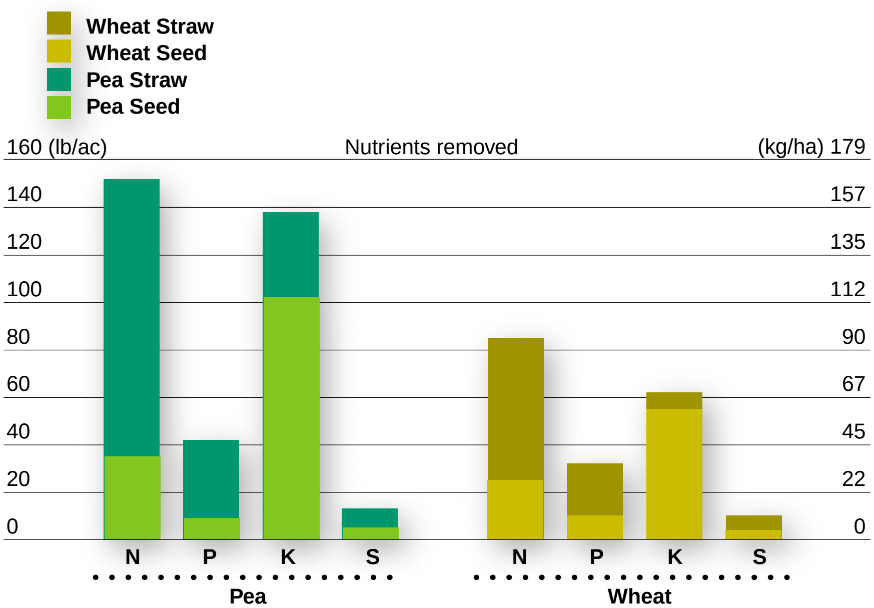


Figure 4.4 *Plant macronutrients removed by field pea and spring wheat.*

whereas most potassium is accumulated in the straw. Figure 4.4 compares macronutrients removed by field pea and spring wheat. With its high yield potential, field pea generally extracts larger amounts of plant nutrients than other pulse crops. Most of the nitrogen accumulated in pulse crops is obtained through nitrogen fixation, but all other nutrients are extracted from native soil sources or fertilizer additions.

- **Fertilizer requirements are always best determined by soil test.**
- **Most pulse fields are not soil tested in the year of production. Rather producers rely on nitrogen fixation for their nitrogen needs.**
- **Some fields may contain high levels of residual soil nitrogen which inhibit symbiotic nitrogen fixation and**
- **Other macro and micronutrients may be limiting for optimal yields.**

If a nutrient deficiency is suspected, a combination of soil and plant tissue sampling should be considered to verify the nutrient levels and to develop the most effective strategy for correcting the problem. Most deficiency symptoms occur in isolated areas or parts of a field, although nitrogen and sulphur deficiencies can be widespread. It is important that, when soil and/or plant tissue samples are taken, separate samples be obtained from the affected area as well as unaffected areas within the same field for comparison purposes. Check with an accredited soil testing laboratory as to sampling, frequency, and handling procedures.

Nitrogen

Symbiotic nitrogen fixation requires the transfer of energy from the pulse plant to the rhizobia in the nodule. If nitrogen is readily available in the soil, the plant will preferentially use it, rather than supply the extra energy for nitrogen fixation. Therefore, the potential benefit of nitrogen fixation is lost, if excess soil and/or fertilizer nitrogen is present. The amount of nitrogen needed to inhibit fixation varies because the initiation of nodules depends on many factors and the level of available nitrogen is just one of these factors. As a general rule, if soil testing indicates soil nitrate nitrogen levels greater than 30 lb/ac (34 kg/ha), addition of fertilizer nitrogen will likely reduce fixation. Nodulation is likely to occur, but the number of nodules may be reduced or the initiation of nodules may be set back. If the combined levels of soil and fertilizer nitrogen are greater than 50 lb/ac (56 kg/ha), the nitrogen fixation process, including the initiation and functioning of nodules, likely will be severely limited.

Should "starter nitrogen fertilizer" be applied for pulse crop production? The answer depends upon the pulse crop being grown and the area of crop production. The idea behind fertilizing with low rates of nitrogen (i.e., 10 – 30 lb/ac or 11 – 34 kg/ha of N), or "starter nitrogen", is based on the fact that it takes approximately three to four weeks after emergence for nodules to establish and become fully functional. After this time active nitrogen fixation will provide most of the nitrogen needs of the plant, but until fixation is initiated, proponents of using starter nitrogen argue the plants will benefit from a little fertilizer nitrogen. Other producers, however, are convinced they see no yield benefit from using starter nitrogen and simple rely on the ability of the crop to fix the required nitrogen. To confuse the issue,

• **Research results support both sides of the argument.**

Consequently, producers wanting to make a decision about starter nitrogen will have to consider a number of factors before they commit to a fertility plan.

First, it is important to recognize that all pulse crops are not created equal. Some are good fixers, and some are not so good fixers, and some pulses will nodulate and fix under a wide range of conditions whereas others are a little more finicky. Of course, this also means that it is important to consider the environment – both in terms of general climatic conditions that are reflected in the soil zone (e.g., dry Brown, Brown, Dark Brown, Black and Grey) and the climatic conditions of a particular year. For example, producers in the dry Brown soil zone are well acquainted with relatively dry conditions and pea grown in this zone is simply not the same as pea grown in the moist Black soil zone. On the other hand, growers in traditionally dry areas have occasionally been overwhelmed by moisture, and their experiences with pulse crops have in those wet years reflect some of the advantages and disadvantages of these moisture levels. It is reasonable to assume that fertility plans might be different, depending on these different climatic conditions. Finally, you also need to consider the individual field. According to Al Slinkard, in his experience, an important issue to consider is whether or not your pulse crop is being grown on a first-time pulse field versus a repeat field. On first-time fields, starter nitrogen may be advisable, particularly on low nitrogen soils because of the delay in getting all of the pulse plants fixing nitrogen at a maximum level. In the dry soil zones, one need not worry about whether or not this starter nitrogen will cause excess growth.

So what do you need to know about the crop you are planning to grow, and the environmental factors that you need to consider? Start with the crop: Several studies on nitrogen fixation indicate that the amount of fixation varies widely among crops, and that within crop types, estimates vary among different research trials – evidence that the amount of nitrogen fixed depends on the environment in any given year and at any given location.

However, a pattern emerges from these trials that researchers are in relative agreement on,

• **Pea and kabuli chickpea are really good nodulators and nitrogen fixers,**

• **Lentil and desi chickpea are also good fixers under ideal environments (although lentil and desi chickpea in particular may be a little sensitive to adverse environment conditions), and**

• **Dry bean is just a poor fixer - period.**

From here, it is important to make the connection with nitrogen requirements. If pea and kabuli chickpea are efficient nitrogen fixers, they are least likely to respond to starter nitrogen. Bean, on the other hand, needs all the help it can get and so dry bean is a good candidate for starter nitrogen application. Lentil, being somewhere in the middle, is a little trickier. Starter nitrogen may be advantageous in some situations, but a lot of evidence indicates that this is not always the case. Here is where we need to start considering environment.

Let's start with the worst nitrogen fixer – dry bean. Agriculture and Agri-Food Canada Morden Research Station research has indicated that low rates of nitrogen fertilizer (27 lb/ac or 30 kg/ha of N) increased yield, with or without inoculation of bean. However, the research indicates that the application of approximately 89 lb/ac (100 kg/ha) of nitrogen gave the optimum yield of dry bean. Typically, the yield responses observed were approximately 30% as compared to inoculant alone. In Saskatchewan, the Department of Plant Sciences examined the response of bean to nitrogen application in 1999. The study included four nitrogen rates (0, 25, 50 and 75 kg/ha N), with and without inoculation, at three sites (Rosthern, Saskatoon, and Melfort). With the exception of black bean grown at Rosthern, a positive yield response to the nitrogen application occurred in all cases. Dry bean yields were still responding at 67 lb/ac (75 kg/ha) of nitrogen, irrespective of inoculation. These studies are ongoing. It appears that bean is not your average pulse crop. In fact, we may need to readjust our thinking when it comes to bean production. It may be that the management system for dry bean is completely unlike any other pulse crop. In fact, it is possible that dry bean should be managed more like the way we manage canola production – which includes using relatively high rates of nitrogen fertilizer.

Let's consider our best nitrogen fixer – field pea. Agriculture and Agri-Food research in the Black soil zone in Saskatchewan reports that field pea, grown in this soil zone, rarely benefits from the application of starter nitrogen. Response to starter nitrogen was observed in a few isolated trials, but the responses were marginal and were not economically important. Moreover, these responses only occurred when a liquid inoculant was used; no starter nitrogen responses occurred for peas inoculated with either peat-based powder or granular inoculants. Research at Beaverlodge examined the effectiveness of inoculant formulation and added starter nitrogen on nodulation, dry matter production and seed yield of field pea. The results revealed that starter nitrogen enhanced dry matter production of pea at the flatpod stage. However, the increase in dry matter production did not translate into increased seed yields. In fact, the seed yield of pea receiving no fertilizer nitrogen, but inoculated with a granular peat formulation (i.e., soil implant), typically was greater than the seed yield of pea inoculated with peat powder or liquid, at starter nitrogen rates ranging from 0 – 72 lb/ac N (0 – 80 kg/ha N). It was concluded that an effective inoculant could provide all the nitrogen that a pea plant requires, particularly when soil nitrogen test levels are low. These results suggest that choosing fields with limited soil nitrogen levels will enhance field pea yield stability because the nitrogen fixation process will be more effective. In most of these studies, adding starter nitrogen did not increase the seed yield of pea. In cases where yield was increased, the potential yield was limited. It is suggested that in the Black soil zone, a starter nitrogen response can only be expected if inoculation fails.

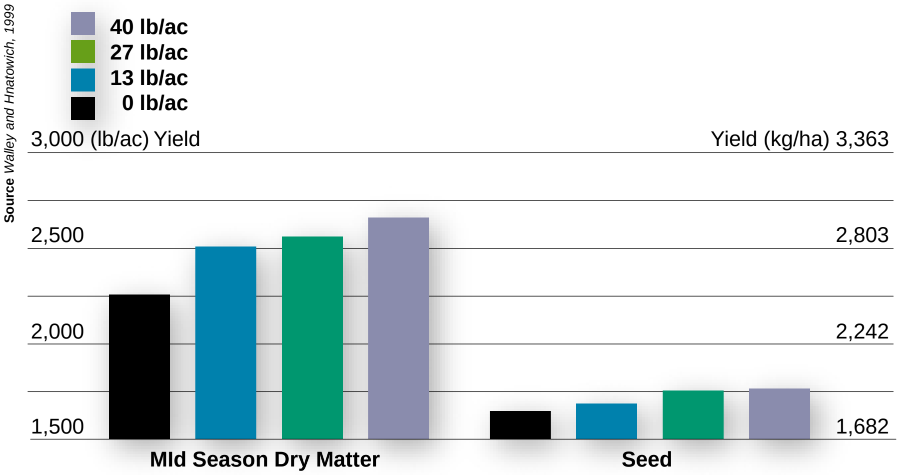
What happens when pea is grown in the drier soil zones? Well-inoculated pulses generally do not benefit from starter nitrogen, but specific environmental conditions may adversely affect nodulation and, thereby, increase the potential for a starter nitrogen response. There are two factors that really affect the need to use starter nitrogen and both are related to the initiation of nodule formation;

- **low temperatures and**
- **drought.**

Early seeding (late April) in the southwest is common, and, if soil temperatures have not yet warmed sufficiently or cold conditions prevail after seeding, nodulation can be inhibited. The second problem occurs, if pea seed is planted into a dry seedbed, and rhizobia survival is reduced. Fortunately, pea plants are great nodulators and of any pulse, they seem the best at overcoming adverse conditions early on and they still may not respond to starter nitrogen. However, Alberta Agriculture has been conducting trials with pea in all soil zones in Alberta. Based on these results, it was concluded that pea seed grown in the drier regions of Alberta (i.e., Brown and Dark Brown) generally will benefit from a starter application of 20 lb/ac N (22 kg/ha N). Additions of higher fertilizer applications were of no further benefit. When similar trials were conducted in the Thin Black soil zone, no benefits to starter nitrogen were observed. From these trials it was concluded that, if soil test nitrogen levels are less than 20 lb/ac N (22 kg/ha N), and the pea is being seeded onto stubble in a continuously cropped field, starter nitrogen may be beneficial in the drier soil zones. However, even in these zones, pea plants grown on fallow probably won't need the starter nitrogen.

Recent research conducted on chickpea has failed to reveal a starter nitrogen response for kabuli chickpea in the Dark Brown and Brown soil zones over a three-year period. Desi chickpea, however, were a little more sensitive to climate than the kabuli and in two out of eight studies, a positive response to starter nitrogen occurred. At both these sites, the conditions were very dry and the plants were faced with droughty conditions early in the growing season. It was suggested that desi chickpea may not be a strong nitrogen fixer and under stress, might benefit from starter nitrogen. That being said, the responses to starter nitrogen (40 lb/ac or 45 kg/ha) were generally less that 200 lb/acre (224 kg/ha), and again, only occurred in a minority of cases. Figure 4.5 outlines the response to fertilizer nitrogen that often occurs. This is a typical response commonly observed with pulse crops; mid-season biomass is increased with nitrogen fertilizer

Figure 4.5 *Influence of starter nitrogen fertilizer on mid-season dry matter yield and seed yield of kabuli chickpea.*



additions. These responses are often visually apparent, nitrogen applications result in plants that are visually darker green and result in a denser crop canopy prior to flowering. Unfortunately, these vegetative responses often do not translate to seed yield increases,

• Our growing season is simply too short to allow conversion of the biomass to potential seed yield.

We are still on the learning curve with chickpea but, so far, it appears that kabuli chickpea is likely a bit more aggressive nodulator than desi chickpea. Apparently, kabuli chickpea and pea are relatively similar in terms of their ability to nodulate, and, thus, their need for starter nitrogen. Lentil and desi chickpea, however, apparently are less efficient nitrogen fixers.

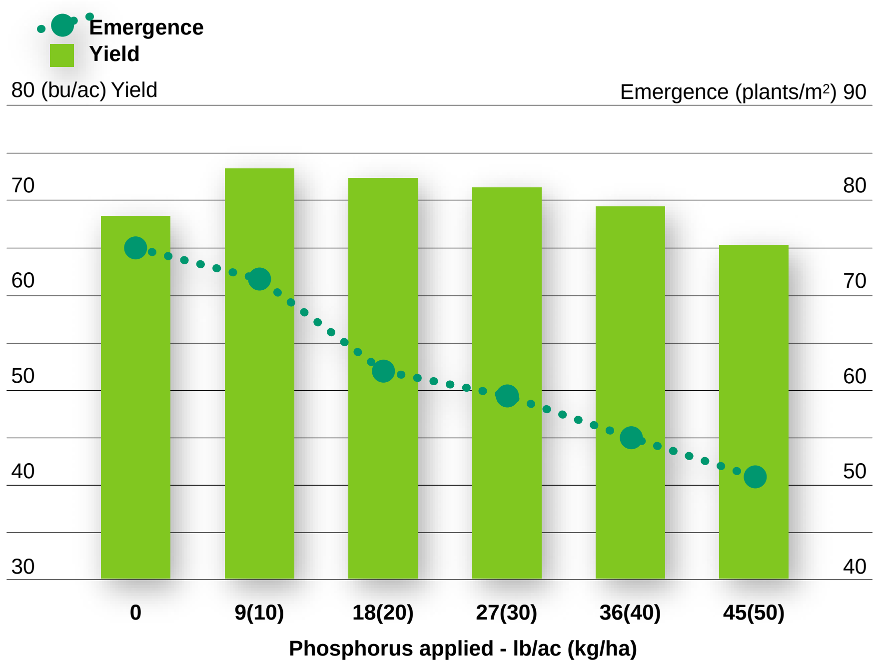
Lentil and desi chickpea in the drier zones may benefit from a little starter nitrogen, but likely only if it is really dry. However, if starter nitrogen is applied to lentil and desi chickpea, no more than 20 lb/ac N (22 kg/ha N) should be applied. Additional amounts may produce vegetative growth, but fail to convert this material into a yield response. However, if moisture conditions are good, the starter nitrogen may simply increase the vegetative growth and set up conditions favouring disease development. This could be especially important for late maturing indeterminate lentil varieties like Laird, especially if seeded late.

The starter nitrogen issue is not completely clear-cut. Producers need to evaluate their own situation and stay away from generalizations. What may work for one producer may not be appropriate for the next. It becomes a matter of evaluating the pluses and minuses of any management decision. For example, the plus to starter nitrogen may be increased yield in some situations. At the same time, however, we know that starter nitrogen typically enhances vegetative growth and, in a wet year, too much vegetative growth may set the crop up for a disease problem, or the crop may not mature before the first frost. These risks are clearly a bigger factor in the moist Dark Brown and Black soil zone with chickpea and Laird lentil, or in years where excess moisture may be a problem. So, if the pluses outweigh the minuses, starter nitrogen could be considered. But if the minuses have the advantage (i.e., no yield benefit, potential for promoting excess vegetative growth and greater disease incidence, etc.) starter nitrogen would be ill advised. However, if starter nitrogen is not used, the plant is going to be relying on nitrogen fixation for its nitrogen – so it's important to ensure that proper inoculation of seed occurs.

Phosphorus

Proper phosphorus fertility is essential for optimum yield, nitrogen fixation and enhancing crop maturity. Plants deficient in phosphorus exhibit spindly top growth with little branching, reduced root growth, less vigor and more susceptibility to diseases, delayed maturity and low

Figure 4.6 *Effect of seedrow phosphorus fertilizer on yield and emergence of pea.*



Source *N. Flore, Westco, personal communication*

yield. Saskatchewan soils may contain up to 2000 lb/ac (2242 kg/ha) of phosphorus. However only a small fraction, approximately 1%, is availably in a plant available form. The best way to assess phosphorus fertility requirements is through a soil test.

Pulse crops are sensitive to seedrow fertilizer. In Saskatchewan it is recommended that no more than 15 – 20 lb/ac (17 - 22 kg/ha) of P_2O_5 be applied with the seed. Field pea is more sensitive to seedrow fertilizer than lentil. Apparently, chickpea and dry bean are also sensitive. Figure 4.6 outlines the effect of seedplaced phosphorus on yield and plant emergence of field pea. In this trial field pea yield increased with the first addition of phosphorus fertilizer, further additions did not increase yield, and additions in excess of 27 lb/ac (30 kg/ha) began depressing yields. Plant emergence declined with each addition of seedplaced fertilizer. For further information on fertilizer application see – Fertilizer Placement. Yield responses to phosphorus fertilizer usually occur when seed is planted into cold, dry soils, on land inherently low in soil phosphorus or on soils with a limited history of phosphorus fertilizer applications.

Small amounts of phosphate may be applied with the seed, if soil tests indicate it is needed.

• The maximum safe amount of phosphate to apply with the seed is 20 lb/ac (22 kg/ha) for lentil, and 15 lb/ac (17 kg/ha) for pea, chickpea, and dry bean.

General phosphate fertilizer recommendations are shown in Table 4.3.

JumpStart from Philom Bios is a fungal inoculant that enhances phosphorus solubility and thus uptake by plants. The fungus colonizes along the root system of the plant, and through, in part, the production of organic acids, increases the solubility of soil or fertilizer phosphorus. Keep in mind that JumpStart will normally replace approximately 10 lb/ac (11 kg/ha) of P_2O_5 fertilizer; therefore, JumpStart should be used in conjunction with phosphorus fertilizer, particularly in cool spring conditions. JumpStart has no residual effect.

Pre-inoculated seed containing JumpStart can be purchased from authorized seed processors or the seed can be treated on-farm with a wettable powder application. It is compatible with all nitrogen-fixing rhizobial inoculants and some seed-applied pesticides.

Table 4.3 *Phosphate fertilizer recommendations (modified Kelowna method).*

Soil test P content in 0 - 6 inches		P_2O_5 recommendations	
lb/ac	**(kg/ha)**	**lb/ac**	**(kg/ha)**
0 – 10	(0 – 11)	30 – 40	(34 – 45)
11 – 20	(12 – 22)	20 – 30	(22 – 34)
21 – 30	(24 – 34)	15 – 25	(17 – 28)
31 – 59	(35 – 66)	10 – 20	(11 – 22)
60+	(67+)	5 – 10	(6 – 11)

Source *Enviro-Test Laboratories.*

Table 4.4 *Potassium fertilizer recommendations (modified Kelowna method).*

Soil test K content in 0 – 6 inches		K_2O recommendations	
lb/ac	(kg/ha)	lb/ac	(kg/ha)
0 – 60	(0 – 67)	140 – 190	(157 – 213)
61 – 90	(68 – 101)	110 – 130	(123 – 146)
91 – 120	(102 – 135)	101 – 120	(101 – 135)
121 – 150	(136 – 168)	80 – 90	(90 – 101)
151 – 180	(169 – 202)	50 – 60	(56 – 67)
181 – 250	(203 – 280)	10 – 20	(11 – 22)
250+	(280+)	0 – 15	(0 – 17)

Source *Enviro-Test Laboratories.*

Research in Manitoba has indicated that dry bean responses to fertilizer phosphorus additions have been limited. It has been suggested that residual soil phosphorus may be more important to dry bean production than applied phosphorus fertilizer. Apparently pulse crops, in general, are effective scavengers of soil phosphorus.

Potassium

Potassium is usually not required in most soils, but deficiencies may exist in Black and Grey soils. Soil tests should indicate whether a problem exists. Soil tests can show adequate potassium reserves, but the crop may not access it due to other factors. Over 130 lb/ac (146 kg/ha) of potassium is needed to grow a 50 bu/ac (3360 kg/ha) pea crop. (The potassium requirement of pea is high, especially during flowering and early pod filling.) Generally, potassium fertilizer should be used any time soil tests show levels are too low. When soil test levels are very low, at least some should be seed placed. However, seed placing potassium may cause seedling damage. As with phosphate, a wider seed row may allow for slightly higher than recommended seed-placed rates as direct seed to fertilizer contact is reduced. More information on potassium fertilization is available in "Farm Facts, Potassium and Chloride Fertilization in Crop Production" available from Saskatchewan Agriculture and Food.

General potassium fertilizer recommendations are shown in Table 4.4.

Sulphur

Sulphur deficiencies usually occur in small areas within a field. Thus, pulse crops should be visually checked for sulphur deficiency symptoms and, if a deficiency is suspected, they should be tissue tested. Even flat fields with no apparent soil change can have extensive fluctuations in sulphur content. The pea sulphur requirement, which is in the 10 lb/ac (11 kg/ha) range, is similar to that of wheat. The symptoms of sulphur deficiency are a yellowing of the plant from the top downward. The plant will have the general appearance of a plant with nitrogen deficiency, except that the top leaves yellow first. Numerous pulse fields in 1999 exhibited yellowing of leaf material though a rhizobial inoculant was applied. Some producers presumed, or were led to believe, that their crop was sulphur deficient. This was not the case. These fields had received abundant rainfall and nitrogen fixation was being affected by excessive soil moisture, resulting in a nitrogen stress. Visual deficiency symptoms disappeared as these soils drained. Additions of soluble sulphur to pulse crops have generally failed to indicate yield responses to sulphur fertilizer application.

Elemental sulphur is not available to the plants during the year of application. A sulphate form of sulphur fertilizer must be applied so sulphur can be available in the year of production, or to correct a visual deficiency. Elemental sulphur products are valuable in a soil sulphur-building program, if applied annually for a number of years as a broadcast application. Elemental products containing bentonite clay are most effective if broadcast and left undisturbed on the soil surface. Banding or seedplacing these forms prevents the fertilizer from oxidizing to the plant-available form as the soil acts as a physical barrier preventing dispersion of the elemental material.

Sulphur can be blended with some fertilizers, but not with ammonium nitrate. In cases where poor sulphur availability occurs along with low levels of nitrogen, sulphur requirements can be provided in the crop year by using ammonium sulphate (20 or 21-0-0) at the rate needed to provide the sulphur requirements. Sulphur can also be applied in the crop year as a liquid fertilizer by using liquid ammonium thiosulphate, which can be blended with most non-acid liquid fertilizers.

General sulphur fertilizer recommendations are shown in Table 4.5.

Table 4.5 *Sulphur fertilizer recommendations (modified Kelowna method).*

Soil test SO_4 content in 0 – 12 in.		SO_4 recommendations	
lb/ac	(kg/ha)	lb/ac	(kg/ha)
0 – 10	(0 – 11)	5 – 20	(6 – 22)
11 – 40	(12 – 45)	0 – 10	(0 – 11)
40+	(45+)	0	0

Source *Enviro-Test Laboratories.*

Micronutrients

Micronutrient deficiencies in Saskatchewan pulse crops are rare. Deficiency symptoms of one micronutrient are often very similar to another, usually exhibiting chlorosis (yellowing) between leaf veins with the veins remaining green. Considering the cost of micronutrient fertilizers and the possibility of misdiagnosis, it is very important to confirm an actual micronutrient deficiency through plant tissue testing and soil sampling. Consult your local Saskatchewan Agriculture and Food agrologist or preferred soil testing lab as to appropriate sampling procedures. Micronutrients are often most effective when broadcast and incorporated or applied as a foliar application. Broadcast applications of 5 – 10 lb/ac (6 – 11 kg/ha) of copper, zinc, iron or manganese sulphates or oxides generally provide sufficient nutrients for 5 – 10 years. Foliar applications of chelated micronutrients can effectively correct deficiency symptoms.

If a micronutrient deficiency is to occur in Saskatchewan, it will probably occur with zinc in dry bean production. Some varieties are known to be inefficient for zinc uptake, and symptoms of inefficiency may be expressed as delayed maturity. CDC Expresso, for instance, is known to be zinc-inefficient. Bean fields on irrigated, sandy soils should be regularly scouted for indications of zinc deficiency. However, research to-date has not shown a requirement for zinc fertilizer applications to bean on irrigated soils.

Soil test levels of some micronutrients are shown in Table 4.6.

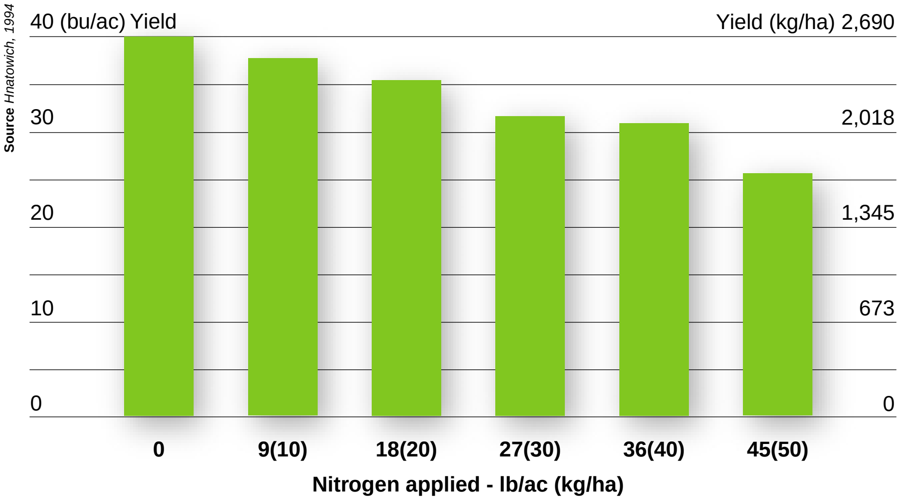
Table 4.6 *Soil testing micronutrient guidelines for Saskatchewan.*

Nutrient	Concentration range (lb/ac)*			
	Deficient**	Marginal	Optimum	High
Zinc (0-6")	< 0.5	0.5 – 1.0	1.0 – 15.0	15.0+
Copper (0-6")	< 1.2	1.2 – 2.0	2.0 – 16.0	16.0+
Manganese (0-6")	< 1.0	1.0 – 2.0	2.0 – 40.0	40.0+
B (0-6")***	< 0.5	0.5 – 1.0	1.0 – 7.0	7.0+

*Multiply lb/ac x 1.121 to get kg/ha **Loam soil ***Low B-using crops

Source *Enviro-Test Laboratories.*

Figure 4.7 *Effect of seed-placed nitrogen on pea yield. Yield declines are due in part to plant stand reductions and reduced nitrogen fixation (not shown).*



Pulses also require several other micronutrients, but they do not normally limit yield. If a deficiency is suspected, soil and tissue testing is recommended.

Fertilizer Placement

Increasing evidence suggests that pulse crops, in general, and field pea, in particular, are sensitive to low-rates of seed-placed fertilizer. If possible, most fertilizer applications should be positioned away from the seed.

Nitrogen fertilizer, in particular, can result in seedling damage.

• Nitrogen fertilizers should not be placed with the seed, but may be applied before seeding or side banded, if good separation from the seed is maintained.

With seed-placed fertilizer, urea (46-0-0) or urea-containing fertilizers, such as liquid urea ammonium nitrate (28 or 32-0-0) are more damaging than ammonium nitrate (34-0-0). As urea breaks down, it produces ammonium carbonate, causing high pH around the fertilizer granule. This results in the production of ammonia gas that is highly toxic to germinating seed. Greater toxicity has been seen where the seedbed has been left loose and dry, and in consequence holds less moisture to dilute the concentrated salt solution from the dissolving fertilizer. Even small amounts of fertilizer nitrogen can result in reduced emergence and consequent yield loss (Figure 4.7). Seedling damage to seedplaced fertilizer is less likely as seedbed moisture, clay, organic matter, and seedbed utilization increase and row spacing decreases.

With fertilizer placed close to the seed, contact between highly concentrated solutions and the seedling is more likely. Seeders such as air seeders, especially those with wider boots and points, often scatter seed and fertilizer, which reduces the proximity of seed and fertilizer. Sideband openers, used in direct seeding systems, should provide adequate separation of seed and fertilizer, unless high operating speed during seeding and/or worn openers result in lack of separation. In a recent study at a number of locations in Saskatchewan the effect of seed-placing or side banding a multi-nutrient fertilizer blend was assessed on pea yield. During the two years of the trial fertilizer additions resulted in significant yield increases at two sites (Figure 4.8), yield reductions at two sites, and no effect on yield at seven sites. However, yield responses were most frequent when fertilizer was separated from the seed.

Figure 4.8 *Influence of placement of a multi-nutrient fertilizer on pea yield.*