AGRI-FACTS
Practical Information for Alberta's Agriculture Industry

Revised January 2013 Agdex 542-3

Phosphorus Fertilizer Application in Crop Production

Phosphorus (P) is an essential plant nutrient required for optimum crop production. Phosphorus deficiencies can be corrected with phosphate fertilizer (P_2O_5). Generally, P is the second most limiting soil nutrient in crop production in Alberta. With respect to fertilizer use, it is second only to nitrogen (N) in Alberta.

Effect on crop growth

Plants need phosphorus for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division. Phosphorus compounds are involved in the transfer and storage of energy within plants. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction.

Phosphorus is readily translocated within plants, moving from older to younger tissues as the plant forms cells and develops roots, stems and leaves.

Adequate P results in rapid growth and early maturity, which is important in areas where frost is a concern. Frequently, P will enhance the quality of vegetative crop growth.

An adequate supply of available P in soil is associated with increased root growth, which means roots can explore more soil for nutrients and moisture. Phosphorus occurs in most plants in concentrations between 0.1 and 0.4 per cent, on a dry weight basis. A deficiency of P will slow overall plant growth and delay crop maturity.

Content and crop requirements

In young, actively growing plants, P is most abundant in the actively growing tissue. By the time plants have attained about 25 per cent of their total dry weight, they may have accumulated as much as 75 per cent of their total phosphorus requirements. Therefore, most crops require significant quantities of P during the early stages of growth. For example, cereal crops will often take up to 75 per cent of their P requirements within 40 days after crop emergence.

Phosphorus requirements for optimum yields vary with different crops (see Table 1). For example, wheat requires less P than canola due to the lower protein content of the seed. A 2,700 kg/ha (40 bu/ac) wheat crop requires about 33 kg/ha (29 lb/ac) of phosphate as indicated in Table 1.

Table 1. Approximate range of phosphate requirements of wheat, barley, canola and pea

Crop	Crop part	Phosphate kg/ha	Phosphate lb/ac
Wheat 2,690 kg/ha (40 bu/ac)	Seed	23 - 28	21 - 26
	Total Uptake	32 - 38	29 - 35
Barley 3,226 kg/ha (80 bu/ac)	Seed	33 - 40	30 - 37
	Total	44 - 53	40 - 49
Canola 1,960 kg/ha (35 bu/ac)	Seed	36 - 44	33 - 40
	Total	50 - 61	46 - 57
Pea 3360 kg/ha (50 bu/ac)	Seed	34 - 41	31 - 38
	Total	41 - 50	38 - 46

Deficiency symptoms

A mild P deficiency results in somewhat stunted crop growth, which can be difficult to see. In severe cases of P deficiency, symptoms include characteristic stunting, purpling or browning, appearing first on the lower leaves and base of the stem and working upward on the plant, particularly on cereal crops. The effect is first evident on leaf tips, and then progresses toward the base. Eventually, the leaf tip dies. However, visual diagnosis of

P deficiency is very difficult and must be confirmed with soil tests and possibly with the aid of plant tissue analysis.

Symptoms are most pronounced in young plants because their more rapid growth makes greater demands on the available supply. Crops seldom completely outgrow a P deficiency; the symptoms often persist to delay maturity.

Soil phosphorus

"Plant-available soil phosphorus" is a term used to mean the portion of soil P that can be taken up from soil by crop roots. It also refers to the portion of soil P extracted by various methods in soil testing laboratories.

In their native state prior to cultivation, Alberta soils often had total soil P levels in the range of 1,100 to 1,350 kg/ha (1,000 - 1,200 lb/ac) in the top 15 cm (6 inches). However, the portion of usable or plant-available P in native soils was very low. Much of the native soil P is contained in soil minerals and in soil organic matter in forms that remain unavailable to plants.

The phosphorus available to plants can be assessed by measuring the phosphate concentration in the soil solution and the soil's ability to maintain the soil solution concentration. The quantity of P in the soil solution, even when at relatively high levels, is only in the range of 0.3 to 3.0 kg/ha (0.3 - 3.0 lb/ac). Rapidly growing crops will absorb about 1 kg/ha (1.0 lb/ac) of P per day.

Therefore, soil solution P must be replenished by the "labile" pool of soil P. Labile P is a pool of soil P that is less available to plants but can undergo rapid chemical or biological changes to recharge or replenish the available P.

Field research in Alberta with a different number of P soil testing methods has shown that the best soil test method for determining plant-available P, called the modified Kelowna method, performs more effectively over a wide range of Alberta soil types.

Remember that soil tests cannot predict with 100 per cent accuracy when crops will respond to added phosphate fertilizer. The frequency of crop response to added phosphate fertilizer can be strongly influenced by environmental conditions, particularly soil temperature and moisture.

For example, at research sites in Alberta with wetter, cooler spring soil conditions, the observed response to phosphate fertilizer, particularly with wheat, barley and canola, tended to be greater than in sites with warmer, drier spring soil conditions. Therefore, producers can expect greater crop response to phosphate fertilizer in a year with wetter and/or cooler spring conditions than in a year with warmer, drier conditions. As a result, soil test recommendations cannot be 100 per cent accurate at predicting when crops will respond to phosphate fertilizer.

It is also important to note that P levels in some soils have increased over the years as a result of repeated annual commercial fertilizer P application or frequent livestock manure application. Consequently, crops grown on some soil types, with higher versus lower soil P levels, are less responsive to fertilizer P application. Additionally, factors such as rate of P fertilizer applied and method of application used can all affect P uptake.

Crop response to applied P fertilizer depends, to a large extent, on the quantity of plant-available P already in the soil. Table 2 gives the general soil test ratings for P. The soil test ratings are normally based on a 0 to 15 cm (0 - 6 inch) sample depth because P is not very mobile in the soil. Therefore, the concentration of P is greatest in the surface soil.

Table 2. Soil test rating for plant-available P levels

Soil test level rating	Phosphorus (P) (lb/ac)
Very low	0 - 20
Low	20 - 35
Medium	35 - 50
High	50 - 80
Very high	greater than 80

Soil P occurs in both organic and inorganic (mineral) forms. Most Alberta soils are relatively low in minerals that contain P, resulting in low plant-available P. Organic P is contained in organic matter and is released slowly by soil micro-organisms.

Micro-organisms

Some soil P is contained in soil micro-organisms. A proportion of inorganic P may be "biologically fixed" by micro-organisms when soil P levels are low. In some cases, micro-organisms may even compete with plants for P when soil P levels are low.

Phosphorus is temporarily tied up in the organic components of micro-organisms; however, this P is eventually returned to the soil when microbes die and break down. After mineralization (conversion from organic P to inorganic P), soil P can be taken up by plants.

Soil pH

Plant availability of P can be affected by soil pH. For example, some P forms are absorbed more readily than other forms. Generally, soil P is slightly more available in a pH range of 6.0 to 7.5 pH.

At higher pH levels (>7.5), calcium may react with phosphorus, creating forms that have slightly lower

availability to plants. Magnesium acts in the same manner, forming different types of magnesium phosphate compounds.

In more acidic soils (pH <6.0), iron and aluminum increase, which causes either a fixing or removing of P from the soil solution. This action greatly limits the availability of inorganic P to plants at soil pH levels <5.0.

As a general rule, the maximum availability of P occurs in Alberta soils within a pH range of 6.0 to 7.5.

Soil moisture and temperature

In general, soil moisture and temperature affect P availability and root growth. In cool, wet soils, P availability and movement are reduced. As a result, crops are more responsive to phosphate fertilizer in cool, wet spring conditions than in warmer, drier spring conditions.

Optimal soil moisture and temperature can help accelerate microbe activity, thereby releasing more P from organic matter. Adequate soil moisture will enhance fertilizer solution and reaction in the soil. As well, moisture will promote plant growth, so P and other nutrient requirements are generally higher for crops grown under irrigation or in higher rainfall areas.

Common phosphorus fertilizer types

Two of the more common phosphate fertilizers sold in Alberta are shown in Table 3.

Table 3. Common phosphate fertilizer types sold in Alberta

Name	Type	Form
Mono-ammonium phosphate	12-51-0	Granular
Ammonium polyphosphate	10-34-0	Liquid

Mono-ammonium phosphate (ortho phosphate), which is the most common form of phosphate used in Alberta, can be safely blended with urea or ESN to produce various blends. It can also be blended with muriate of potash (0-0-60; 0-0-62) or with most sulphur fertilizers as well.

Most soil testing laboratories in Alberta report soil test P level in lb/ac, but fertilizer recommendations are made in terms of phosphate ($P_2 0_5$) in lb/ac. To convert P to $P_2 0_5$, multiply by 2.3 (e.g. 10 lb/ac of P = 23 lb/ac of $P_2 0_5$). Phosphorus fertilizer in Canada is sold on the basis of $P_2 0_5$ in per cent of total product.

Phosphate fertilizer application

There are a number of methods of applying P fertilizer. Figure 1 shows examples of fertilizer placement; however, some methods are more efficient than others. To obtain good P fertilizer efficiency, adequate rates of nitrogen and other nutrients must be available to the crop.

Broadcast and incorporation

The broadcast and incorporation method involves uniformly broadcasting and incorporating P fertilizer onto the soil before seeding. At low and medium soil test levels for P, the broadcast and incorporation method is much less effective than seed-placed or banded P.

When P is broadcast and incorporated, application rates may have to be two to four times the in-row banded rate to obtain an equal crop response when soil test P level is very low. Therefore, broadcast and incorporation of P may not be economical or practical if high rates are needed to increase yield.

However, high rates of broadcast and incorporated P on eroded soil areas or knolls are recommended to even out the fertility of eroded fields because these fields are often low in soil P. Eroded soils are often very responsive to P fertilizer.

Broadcasting P at higher rates involves a high initial cost, but these costs can be recovered over several years. The availability of applied P to plants tends to decrease over a period of years because of the reaction products formed in the soil. However, it is also recommended that the one-time large application be followed by an annual application of seed-placed P fertilizer with annual crops.

When high rates of P fertilizer are applied, it is possible to reduce the availability of micronutrients, particularly zinc (Zn) and copper (Cu). In southern Alberta, where high rates of P have been applied, isolated cases of zinc deficiency have been observed during cool, wet spring conditions in both irrigated field beans and in corn grown on sandy soils where high P rates have been used. In central Alberta, copper deficiency in cereal crops has been associated with higher phosphate fertilizer applications.

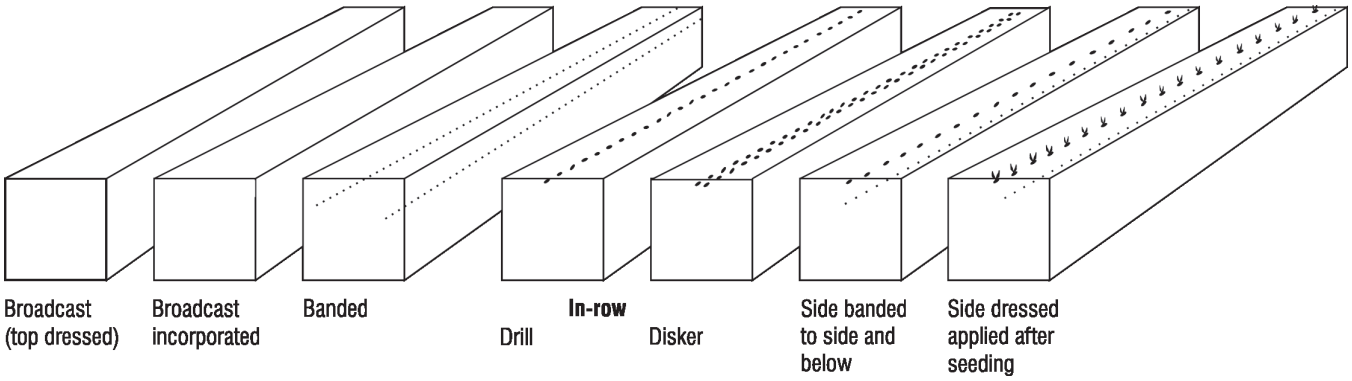

Figure 1. Various methods of phosphate fertilizer application.

Top dress (broadcast - no incorporation)

Broadcasting P fertilizer without incorporation is only recommended for established forage crops because it is the only practical application method currently available. Granular phosphate can be broadcast. Liquid phosphate fertilizer (e.g. 10-34-0) can be dribble banded onto forage stands. There are times where dribble-banded liquid P fertilizer might be superior to a broadcast application of granular P fertilizer. However, liquid fertilizer is generally more expensive per pound of phosphate versus granular fertilizer.

Phosphorus fertilizer is immobile in soil; therefore, plant uptake of fertilizer P may be low in the first year after application. However, alfalfa and grasses do have feeder roots very near the soil surface and can take up some broadcast P fertilizer when surface soil moisture conditions are good.

For forage crops, a three- to four-year supply of P can be either deep banded or broadcast and incorporated before establishment. Subsequent applications may be top dressed. Recent work in southern Alberta showed that annual broadcast P application was as good as and at times superior to a one-time large application of P fertilizer prior to establishment of timothy hay.

Seed-placed phosphorus (banded with seed in the seed row)

The maximum safe rate of P that can be applied with the seed for cereal crops with a 10 per cent seedbed utilization (SBU) is 50 to 70 kg/ha (45 - 65 lb/ac) of $P_2 0_5$ depending on soil moisture conditions and the opener used. For oilseed crops, seed-placed $P_2 0_5$ rates should not exceed 15 kg/ha (14 lb/ac) when a seeding implement that places the seed and fertilizer in a narrow band (10 per cent SBU) is used. For peas, seed-placed $P_2 0_5$ rates should not exceed 30 to 35 kg/ha (27 - 33 lb/ac), especially when a seeding implement that places the seed and fertilizer in a narrow band (double disc drill) is used.

Single and double disc no-till drills cut a fairly narrow furrow and place the seed and fertilizer together in the bottom of the furrow. These drills place the fertilizer in a concentrated band close to the seed and are most likely to result in damage to sensitive crops at higher rates of application.

Hoe-type openers cut a wider furrow, and the seed and fertilizer are scattered across the bottom of the furrow. This scattering in a wider band results in a lower concentration of fertilizer close to the seed and is less likely to cause damage to sensitive crops such as canola or flax when high rates of fertilizer are applied.

Seeding implements that scatter the seed in wide bands (air seeders with sweeps) reduce the seed-fertilizer contact. As a result, higher seed-placed P rates can safely be used.

However, because of the wide variation in furrow opener design and spacing, as well as the width of the seed row, specific maximum safe seed-placed P rates have not been determined for all opener types. Generally, rates can be increased by 25 to 50 per cent over the safe rates for a 10 per cent SBU. At low rates of fertilizer application, response to seed-placed P may be slightly less when the seed and fertilizer are spread out in broad bands as compared to narrower bands.

Side-banding phosphorus

The side-banding method places the P in a band near the seed row during the seeding operation. The fertilizer is commonly banded 2.5 to 5 cm (1 - 2 inches) below and/or to the side of the seed row for small seeded crops and row crops such as sugar beets, potatoes, sunflowers, corn and beans. This method is the best placement option for crops that are sensitive to seed-placed phosphate fertilizer.

Phosphate at all recommended rates can be safely applied with the side-banding method. However, specialized side-banding seeding equipment is required. Yield increases obtained with this placement are nearly equal to seed-placement at low rates of application, but much

superior when application rates are too high for safe placement with the seed. Phosphorus side banded near the seed of cereal crops in most cases is close in efficiency to seed-placed phosphorus.

Some no-till seed drills use a mid-row or paired-row technique. Two rows are seeded about 7.5 to 12 cm (3 - 5 inches) apart, and P is banded between the two rows about 2.5 to 5 cm (1 - 2 inches) below the seeding depth. There is an 18 to 25 cm (7 - 10 inch) space between the next pair of rows. Generally, this method of placement is effective. However, root access to the P fertilizer could be compromised in the following situation: if the fertilizer is 8 cm (3 inches) more to the side and not below the depth of seeding, seeding depth is relatively shallow and soil conditions dry out after seeding.

Banding phosphorus

The banding method of application places P in concentrated bands in the fall or spring before seeding. A cultivator-type implement with shovels or knives is used with a shank spacing of 20 to 35 cm (8 - 14 inches). Depth of application is normally 8 to 10 cm (3 - 4 inches).

Banded P can be somewhat less effective than seed-placed P when banded with N fertilizer just before seeding. However, both seed-placed and banded P are more effective than broadcast and incorporated P when soil test levels are low.

In some locations and years, particularly on very low P soils and when soil temperature is low following seeding, the "starter" effect of phosphate placed with or near the seed can be important and cannot be achieved by banded phosphate alone. For this reason, seed placement of a portion of the P at 11 to 17 kg/ha (10 - 15 lb/ac) $P_2 0_5$ is advised when phosphate is banded.

Banded P may be more effective than seed-placed P under dry surface soil conditions. The major advantages of banding P are as follows:

- rates considered too high for seed-placement with oilseeds and pulse crops can be used where low soil P warrants such rates
- the amount of fertilizer handled at seeding time can be reduced or, in some situations, eliminated

The disadvantage of banding P in the spring is that it may dry out the seedbed, which could reduce germination and limit crop yield under dry spring moisture conditions. This concern is particularly important in southern Alberta in drier spring conditions.

Application of phosphate both with the seed and deep banded (split application) is an effective way to achieve the benefits of both methods.

Narrow spacing between phosphate bands is preferred so that phosphate uptake is not delayed during early growth owing to long distances between the bands and some of the seedlings. On very low P soils, "stripping" can occur, which is caused by poorer growth of plants midway between phosphate bands when the bands are too widely spaced. For phosphate, banded spacings of more than 30 cm (12 inches) are not recommended, and narrower spacings may be more effective, particularly where no phosphate is seed placed.

When banding phosphate, the bands must be sufficiently deep to avoid disruption by subsequent tillage and seeding operations. Time of phosphate banding (fall versus spring) appears to have little effect on fertilizer efficiency.

Plant uptake of phosphate placed in the same band with nitrogen (N) can be restricted. For example, Alberta research has shown that when 60 kg/ha (54 lb/ac) of phosphate was banded with 120 kg/ha (108 lb/ac) of N, phosphate uptake efficiency was only 12 to 15 per cent compared to 30 to 35 per cent when the same rate was placed in a separate band away from the N band.

Generally, phosphate should not be banded with N fertilizer if the N rate is higher than 70 to 80 kg/ha (63 - 72 lb /ac) to avoid reduced uptake efficiency of the P fertilizer. The major reason for this effect is that plant roots cannot penetrate the concentrated nitrogen band and, therefore, cannot take up the P effectively.

Some of the advantages of banding before planting include the following:

- Application of fertilizer during the busy seeding period is avoided. However, some growers may still wisely place some P fertilizer with the seed for starter effects.
- Fertilizer nutrients are strategically placed at depths in the root zone where soils tend to remain moist longer during the early parts of the growing season and where they are beyond the reach of shallow germinating and rooting weeds.

Comparison of placement methods

Placing P fertilizers in bands minimizes the contact between the soil and the P fertilizer. In contrast, mixing the P with soil exposes it to more soil, resulting in reduced plant availability.

Alberta research suggests that placement of P with the seed is frequently better than banded P. Table 4 shows the wheat, barley and canola response to seed-placed versus banded phosphate fertilizer in southern Alberta in 1991 on summerfallow and stubble.

Table 4. Response to seed-placed versus banded phosphate fertilizer						
	Wheat		Barley		Canola	
	Fallow	Stubble	Fallow	Stubble	Fallow	Stubble
Number of sites	7	17	7	19	7	15
P responsive sites	6	10	6	13	6	14
Seed placed > banded	4	6	4	8	5	6
Banded > seed placed	2	3	1	0	0	2
Seed placed = banded	0	1	1	5	1	7

Seed placement of 17 kg/ha (15 lb/ac) is advised when phosphate is banded to obtain a starter effect when soil P levels are very low, 0 to 20 kg/ha (0 - 18 lb/ac) or cool soil temperatures occur after seeding, conditions common in the Black, Gray-Black and Gray soil zones.

Seed-placed P is recommended as it is one of the most efficient means of P application, provided the amounts applied do not injure the germinating seed and seedling. When higher rates of P are used in dry and/or coarse-textured soils, banding away from the seed at planting at times may be superior to placing phosphate with the seed.

Phosphorus fertilizer recommendations

An Alberta research project was conducted in the 1990's to evaluate the responsiveness of wheat, barley and canola to phosphate fertilizer. The research was done on a wide range of soil types across Alberta to determine when each crop will respond to phosphate fertilizer. Table 5 summarizes the number of responsive and unresponsive sites by soil zone based on a two-bushel yield difference between the control treatment and phosphate fertilizer treatments.

In summary, 81 per cent of wheat sites, 90 per cent of barley sites and 72 per cent of canola sites responded to added phosphate fertilizer at the 427 research sites. The high number of sites seen to respond was similar in each of the three years of the project.

Table 5. Summary of responsive and non-responsive sites by soil zone based on yield differences								
Crop	Type of response*	Brown	Dark Brown	Thin Black	Black	Gray Wooded (Central)	Gray Wooded (Peace River)	Total sites
Wheat	Response	9	10	14	21	10	10	74
	Marginal response	1	10	9	8	6	9	43
	No response	6	8	3	6	3	2	28
Barley	Response	9	14	19	32	14	13	101
	Marginal response	5	12	14	3	2	6	42
	No response	2	0	4	4	3	3	16
Canola	Response	3	2	1	9	6	8	29
	Marginal response	8	14	11	12	8	7	60
	No response	5	9	6	8	1	5	34

* Response: yield increase greater than 5 bu/ac. Marginal response: yield increase between 2 and 5 bu/ac. No response: less than 2 bu/ac yield increase.

This research project clearly indicated the importance of phosphate fertilizer in crop production throughout Alberta. Results suggest that approximately 75 per cent of Alberta soils are marginally to severely deficient in soil P, depending on the interpretation of results. Responses were observed in all major soil zones across Alberta.

The frequency of crop response to added phosphate fertilizer was partly influenced by environmental conditions. For example, at sites with wetter, cooler spring conditions, the noticeable response of crops, particularly wheat and barley, tended to be greater than in warmer drier spring conditions.

Phosphate fertilizer recommendations and the probability of response are provided for barley (Tables 6 and 7), wheat (Tables 8 and 9) and canola and mustard (Tables 10 and 11). General phosphate fertilizer recommendations for pulse crops are in Table 12. For general groupings of other crops, see Table 13. The placement recommendation for each group of crops is discussed in relation to soils low in available P where crop response is lower and more variable.

Note that the P recommendations in Alberta are currently designed for placing the phosphate with or near the seed for most crops. These rates are not applicable when P is broadcast and incorporated.

Table 6. Phosphate fertilizer recommendations for barley on a medium to fine textured soil with a neutral pH, based on the Kelowna soil test method. Recommendations are given for each soil zone at three soil moisture condition levels at the time of seeding

Soil test P (lb/ac)	Brown			Dark Brown			Thin Black			Black			Gray Wooded			Irrigated
	D*	M*	W*	D	M	W	D	M	W	D	M	W	D	M	W	
	P_2O_5 lb/ac															
0 -10	30	35	40	35	40	45	40	45	50	40	45	50	40	45	50	50
10 - 20	25	30	35	30	35	40	35	40	45	35	40	45	35	40	45	45
20 - 30	20	25	30	25	30	35	30	35	40	30	35	40	30	35	40	40
30 - 40	15	20	25	20	25	30	25	30	35	25	30	35	25	30	35	35
40 - 50	15	15	20	20	20	25	25	25	30	25	25	30	25	25	30	35
50 - 60	15	15	20	15	15	25	20	20	30	20	20	30	20	20	30	30
60 - 70	15	15	15	15	15	20	15	20	25	15	15	25	15	15	25	25
70 - 80	0	15	15	0	15	15	0	15	20	0	15	20	0	15	20	20
80 - 90	0	0	15	0	0	15	0	0	15	0	0	15	0	0	15	15
>90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Seedbed soil moisture conditions at seeding D = 25%; M = 50%; W = 75% of field capacity.

Table 7. Approximate probability of a greater than 2 bu/ac and 5 bu/ac barley response to phosphate fertilizer when following recommendations

Soil test P (lb/ac)	Brown		Dark Brown		Thin Black		Black		Gray Wooded		Irrigated
	>2	>5	>2	>5	>2	>5	>2	>5	>2	>5	
	%										
0 - 10	95	80	95	85	95	95	95	95	95	90	80
10 - 20	90	70	90	80	95	90	95	90	95	85	70
20 -30	90	60	90	70	90	80	90	80	90	80	60
30 -40	80	55	80	60	85	70	85	70	85	70	55
40 - 50	70	50	70	50	80	60	80	60	80	60	50
50 - 60	60	35	60	35	70	50	70	50	70	50	35
60 - 70	50	30	50	30	50	30	50	30	50	30	30
70 - 80	40	30	40	30	40	30	40	30	40	30	30
>80	35	25	35	25	35	25	35	25	35	25	25

Table 8. Phosphate fertilizer recommendations for spring wheat on a medium to fine textured soil with a neutral pH, based on the Kelowna soil test method. Recommendations are given for each soil zone at three soil moisture condition levels at the time of seeding

Soil test P (lb/ac)	Brown			Dark Brown			Thin Black			Black			Gray Wooded			Irrigated
	D*	M*	W*	D	M	W	D	M	W	D	M	W	D	M	W	
	P_2O_5 lb/ac															
0 - 10	30	35	40	35	40	45	40	45	50	40	45	50	40	45	50	50
10 - 20	25	30	35	30	35	40	35	40	45	35	40	45	35	40	45	45
20 - 30	20	25	30	25	30	35	30	35	40	30	35	40	30	35	40	40
30 - 40	15	20	25	20	25	30	25	30	35	25	30	35	25	30	35	35
40 - 50	15	15	20	20	20	25	25	25	30	25	25	30	25	25	30	35
50 - 60	15	15	20	15	15	25	20	20	30	20	20	30	20	20	30	30
60 - 70	15	15	15	15	15	20	15	20	25	15	15	25	15	15	25	25
70 - 80	0	15	15	0	15	15	0	15	20	0	15	20	0	15	20	20
80 - 90	0	0	15	0	0	15	0	0	15	0	0	15	0	0	15	15
>90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Seedbed soil moisture conditions at seeding D = 25%; M = 50%; W = 75% of field capacity.

Table 9. Approximate probability of a greater than 2 bu/ac and 5 bu/ac wheat response to phosphate fertilizer when following recommendations

Soil test P (lb/ac)	Brown		Dark Brown		Thin Black		Black		Gray Wooded		Irrigated
	>2	>5	>2	>5	>2	>5	>2	>5	>2	>5	
	%										
0 - 10	95	75	95	80	95	95	95	95	95	90	80
10 - 20	90	70	90	75	95	80	95	90	90	80	70
20 - 30	80	60	80	65	90	70	90	80	80	70	60
30 - 40	80	50	70	55	85	60	85	70	75	60	50
40 - 50	60	40	60	45	80	50	80	60	70	50	40
50 - 60	50	30	50	35	70	40	70	50	60	40	30
60 - 70	40	30	40	30	50	30	50	30	50	30	30
70 - 80	30	20	30	25	40	25	40	25	40	25	25
>80	25	20	25	20	30	25	30	25	35	25	25

Cereal crops

Soils low and medium in available P

On most soils low in available P, seed-placed phosphate at recommended rates is equal to or better than banding near the seed and far superior to surface application and incorporation. Recommended phosphate fertilizer should be applied, and the probability of crop response would be in the range of 60 to 100 per cent.

If P is broadcast and incorporated, the annual application rate must be two to four times the rate recommended for seed-placement to obtain equal crop response in the year of application at very low and low soil test P levels.

Soils high in available P

In soils high in available P, seed-placed or banded fertilizer P at rates up to 20 to 30 kg/ha (18 - 27 lb/ac) of P_2O_5 may result in a crop response 30 to 50 per cent of the time, depending on crop, soil zone and environmental conditions (see Tables 7 and 9).

Canola and Mustard

Soils low and medium in available P

On soils low and medium in available P, rates up to 15 kg/ha (14 lb/ac) P_2O_5 can be seed placed using a seedbed

utilization of 10 per cent. Rates greater than 15 kg/ha (14 lb/ac) $P_2 0_5$ should be either banded prior to seeding or side banded at the time of seeding.

Soils high in available P

Seed-placed or banded fertilizer P on soils high in available P at rates up to 15 kg/ha (14 lb/ac) of $P_2 0_5$ may result in a crop response 30 to 50 per cent of the time, depending on soil zone and environmental conditions (see Table 11).

Table 10. Phosphate fertilizer recommendations for canola and mustard on a medium to fine textured soil with a neutral pH, based on the Kelowna soil test method. Recommendations are given for each soil zone at three soil moisture condition levels at the time of seeding

Soil test P (lb/ac)	Brown			Dark Brown			Thin Black			Black			Gray Wooded			Irrigated
	D*	M*	W*	D	M	W	D	M	W	D	M	W	D	M	W	
	$P_2 0_5$ (lb/ac)															
0 -10	30	35	40	35	40	45	40	45	50	40	45	50	40	45	50	50
10 - 20	25	30	35	30	35	40	35	40	45	35	40	45	35	40	45	45
20 - 30	20	25	30	25	30	35	30	35	40	30	35	40	30	35	40	40
30 - 40	15	20	25	20	25	30	25	30	35	25	30	35	25	30	35	35
40 - 50	15	15	20	20	20	25	25	25	30	25	25	30	25	25	30	35
50 - 60	15	15	20	15	15	25	20	20	30	20	20	30	20	20	30	30
60 - 70	15	15	15	15	15	20	15	20	25	15	15	25	15	15	25	25
70 - 80	0	15	15	0	15	15	0	15	20	0	15	20	0	15	20	20
80 - 90	0	0	15	0	0	15	0	0	15	0	0	15	0	0	15	15
>90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Seedbed soil moisture conditions at seeding D = 25%; M = 50%; W = 75% of field capacity.

Table 11. Approximate probability of a greater than 2 bu/ac and 5 bu/ac canola response to phosphate fertilizer when following recommendations

Soil test P (lb/ac)	Brown		Dark Brown		Thin Black		Black		Gray Wooded		Irrigated
	>2	>5	>2	>5	>2	>5	>2	>5	>2	>5	
	%										
0-10	90	70	95	80	95	90	95	95	95	90	95
10 - 20	80	60	90	80	95	85	95	90	95	85	90
20 - 30	70	60	80	70	90	75	90	80	90	75	80
30 - 40	60	50	70	60	80	65	85	70	80	65	70
40 - 50	50	40	60	50	70	55	80	60	70	55	60
50 - 60	40	30	50	40	60	45	70	50	60	45	50
60 - 70	40	30	40	30	50	35	60	40	50	35	40
70 - 80	35	20	35	20	40	30	50	30	40	30	30
80 - 100	30	10	30	15	30	20	40	20	30	20	20

Pea and Lentil

Phosphorus soil tests and fertilizer recommendations developed for pea and lentil in Alberta are fairly effective in predicting when these crops will respond to P fertilizer application. Soils that have accumulated fertilizer P over the years may still test deficient in plant-available P, particularly on high pH calcareous soils. Yet, crops grown on this land may not respond to added P fertilizer. This situation may occur in the Brown and Dark Brown soil areas of southern Alberta.

Table 12 shows phosphate fertilizer recommendations for pea and lentil in Alberta. P fertilizer does not have a strong effect on pulse crops as these crops are fairly efficient at taking up soil P.

Alberta research suggests that pea is most responsive to P fertilizer when soil P levels are less than 30 lb P/ac. Above this level, there is relatively low chance P fertilizer will increase yield. When soil test P levels are medium and significant P fertilizer was applied in the past 10 to 20 years, an annual maintenance application of phosphate fertilizer can be used to meet crop requirements and replenish soil P that is removed.

Phosphate fertilizer applied when soil test P is higher than 30 lb P/ac will help to replace soil P and maintain good soil P levels. See Table 12 for general phosphate fertilizer recommendations for pea and lentil crops.

Flax

Flax does not respond as readily to fertilizer P banded with the seed. Also, flax is sensitive to seed-placed P. See Table 13 for general phosphate fertilizer recommendations.

Soils low in available P

On soils low in available P, the P fertilizer can be seed placed but should not exceed 15 kg/ha (14 lb/ac) $P_2 0_5$, and remaining P should be side banded at seeding or banded prior to seeding.

Soils medium to high in available P

In soils medium to high in available P, banding P prior to seeding or side banding at seeding at rates of 28 kg/ha (25 lb/ac) $P_2 0_5$ may result in a crop response, particularly in cool, wet spring conditions.

Corn, potatoes and sunflowers

See Table 13 for general phosphate fertilizer recommendations for corn, potatoes and sunflowers.

Soils low to medium in available P

On soils low to medium in available P, all P should be banded or side banded at the time of seeding away from the seed row.

Table 12. General phosphate fertilizer recommendations for pea and lentil grown in the various soil zones of Alberta at increasing levels of soil P, based on the Kelowna method of extraction of soil P

Soil test P (lb/ac)	Brown and Dark Brown	Thin Black and Black	Gray Wooded	Irrigated
	$P_2 0_5$ (lb/ac)			
0 - 10	35	40	35	45
10 - 20	30	35	30	40
20 - 30	25	30	25	35
30 - 40	20	25	20	30
40 - 50	15	20	15	25
50 - 60	15	15	15	20
60 - 70	0	15	15	15
>70	0	0	0	0

Soils high in available P

Banding or side-banding P on soils high in available P may result in a crop response 40 per cent of the time.

Sugar beets

See Table 13 for general phosphate fertilizer recommendations for sugar beets.

Soils low to medium in available P

On soils low to medium in available P, up to 22 kg/ha (20 lb/ac) P_2O_5 can be seed placed. Rates greater than 22 kg/ha (20 lb/ac) P_2O_5 should be banded prior to seeding or side banded near the seed.

Soils high in available P

On soils high in available P, banding or side-banding P with or near the seed in these soils may increase seedling vigour but may or may not carry through to increase yield.

Forage crops

The best method and time of fertilizer P application for cultivated grasses, grass-legumes and legumes are broadcast-incorporated or deep banded prior to stand establishment coupled with annual broadcast application as needed. Phosphorus applied in this manner will suffice for the year of establishment and for two to four years after, depending on the initial rate of application, available soil P levels and other soil characteristics.

On soils low in available P, a single high rate (100 to 150 kg/ha or 90 to 135 lb/ac) of P_2O_5 broadcast and incorporated prior to seeding has shown better yield response over a three-year period than an equivalent amount broadcast in annual increments in some situations.

However, P requirements for established forage stands can be supplied by broadcast applications, particularly under irrigated conditions and for wetter areas of the province. In the future, it may be possible to band granular or liquid fertilizers into established forage fields by using very narrow openers or by injecting liquid fertilizer using extremely high pressure. However, this technology has not been developed yet.

For more information on forage crops, see the following:

- *Fertilizing Grasses for Hay and Pasture*, Agdex 127/541-1
- *Fertilizer Requirements of Irrigated Alfalfa*, Agdex 561-18

These factsheets, published by Alberta Agriculture, offer greater detail on this topic.

Table 13. General phosphate fertilizer recommendations for crops grown in Alberta at increasing levels of P in the soil based on the Kelowna method of extraction of soil P

Soil test P (lb/ac)	Flax	Potatoes	Sugar beets	Corn and sunflowers
	P_2O_5 (lb/ac)			
0	35	100	80	70
10	30	90	70	60
20	25	80	60	50
30	20	70	50	40
40	15	60	40	30
50	15	50	30	20
60	15	40	30	20
70	15	40	30	20
80-100	10	30	20	15
>100	0	0	0	0

Summary

For optimum crop production, an adequate supply of P close to the seed during the first six weeks of growth and an adequate amount of P in the soil for the rest of the season are ideal. Placement of P in-row with cereal and oilseed crops has been the traditional method used for P fertilization in Alberta. Pre-plant banding of P with nitrogen has been found to be a good alternative method of application under certain conditions. However, under conditions of low to medium soil P coupled with low soil temperatures, "starter" P in the seed row is frequently very beneficial for annual crops.

More information on soil phosphorus and phosphate fertilization, contact:

- Alberta AgInfo Centre – call toll free in Alberta at 310-FARM (3276)
- fertilizer company agronomists
- soil testing laboratory agronomists
- or visit the Alberta Agriculture website at www.agriculture.alberta.ca

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01/13/200